S. Hrg. 101-596

ESTABLISHING A HYDROGEN RESEARCH AND DEVELOPMENT PROGRAM

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

OF THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED FIRST CONGRESS

SECOND SESSION

ON

S. 639

TO ESTABLISH A HYDROGEN RESEARCH AND DEVELOPMENT PROGRAM

MARCH 30, 1990

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ESTABLISHING A HYDROGEN RESEARCH AND DEVELOPMENT PROGRAM

FRIDAY, MARCH 30, 1990

U.S. SENATE,
SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The subcommittee met, pursuant to notice, at 9:32 a.m., in room SD-366, Dirksen Senate Office Building, Hon. Wendell H. Ford, presiding.

OPENING STATEMENT OF HON. WENDELL H. FORD, U.S. SENATOR FROM KENTUCKY

Senator FORD. Good morning, ladies and gentlemen. I am pleased to be here to chair today's hearing on S. 639, a bill to establish a hydrogen research and development program. This bill was introduced by our fine colleague from Hawaii, Senator Matsunaga, and is co-sponsored by Senators Inouye, Wirth, Pell, Leiberman and Boschwitz.

Over the years, this country's interest in alternative energy sources, such as hydrogen, has risen and fallen with the price of oil. When oil prices are high, interest in hydrogen energy is high. When oil prices are low, interest in hydrogen energy is low.

This is no way, in my opinion, to conduct an energy research and development program. This is no way to develop a national energy policy. We must have a coordinated research and development program. We must have a comprehensive national energy policy. A hydrogen research and development program should be established and should be part of our national energy policy.

Hydrogen is an attractive fuel because it can be produced from water, the earth's most abundant resource. In addition, there is little environmental impact from the burning of hydrogen.

Questions remain, however, about the economics and the environmental performance of hydrogen production, transportation, and storage. These questions can be answered by a coordinated research effort. Senator Matsunaga's bill certainly points us in the right direction, much like his fuel cell research bills—S. 633 and S. 634—point us in the right direction in that area.

Unfortunately, Senator Matsunaga is not able to attend today's hearing, but he has submitted a statement on his legislation. I will place Senator Matsunaga's statement in the record at this point.

[The prepared statement of Senator Matsunaga and the text of S. 639 follow:]

STATEMENT OF U. S. SENATOR SPARK MATSUNAGA
BEFORE THE SENATE ENERGY & NATURAL RESOURCES COMMITTEE
ENERGY RESEARCH & DEVELOPMENT SUBCOMMITTEE
TO CONSIDER S. 639, A BILL FOR A NATIONAL HYDROGEN R&D PROGRAM
366 Dirksen Senate Office Building
Washington, D. C.
Friday, March 30, 1990 - 9:30 a.m.

I am grateful to Chairman Wendell Ford of the Energy Research and Development Subcommittee for scheduling this hearing on my bill, S. 639, to establish a national hydrogen research and development program, as well as for the opportunity to submit this statement in its behalf.

Seldom can a single bill be said to address the gamut of legislative issues, both environmental and economic, facing Congress and the Nation. There needs to be a common thread between global climatic change and those activities spawning greenhouse gases, on the one hand, and the U. S. trade deficit and American competitiveness in world markets, on the other. That common thread is energy, and a national program for hydrogen research and development, as called for in this legislation, is the measure that touches all the aforementioned bases.

The form of energy we use is at the heart of virtually all environmental issues. The location of our energy sources is at the crux of our trade imbalance. And in no area of economic endeavor is overseas competition more keenly felt than in the quest for new energy technologies.

Hydrogen is one of the most abundant elements in the universe, with water, a primary source of hydrogen, covering three-fourths of the Earth. Indeed, hydrogen plays a role in such varied everyday products as peanut butter, vitamin C, and aspirin, not to mention such larger products as clear plate glass windows.

As a transportation fuel, hydrogen's environmental benefits are particularly apparent, as attested by the fact that provisions of this bill are reflected in the global warming legislation sponsored by Senator Tim Wirth as well as in a similar measure sponsored by Congresswoman Claudine Schneider. Moreover, hydrogen can be transported more efficiently and at less cost than electricity over long distances.

If it were not for our dependence upon imported foreign oil, our trade balance would not reflect a deficit but rather a surplus. Hydrogen, then, offers a key to achieving energy security. In addition, our national objective of designing and operating transatmospheric aerospace craft, such as the "Orient Express," is dependent upon the development of hydrogen fuel. Finally, it is increasingly apparent that the United States is falling behind other nations in hydrogen research and demonstration in yet another field of energy technology we ourselves have pioneered.

Only last fall Mercedes-Benz demonstrated a hydrogen-powered vehicle here on Capitol Hill by offering Members of Congress rides in a sedan fueled by low-temperature hydride hydrogen. In 1988 Soviet television announced the triumph of an ordinary airplane flight using hydrogen fuel for the first time and showed the plane in the air with its jet stream of condensing steam instead of the usual kerosene smoke. Since then West Germany has commenced sea tests of a hydrogen fuel cell powered submarine with a range said to be "several times" that of a conventional diesel-electric powered submarine.

On the ground, the Soviets are in the process of turning out 100 hydrogen fuel cell powered vans and have joined forces with the Hungarian bus manufacturer Ikarus to adapt a 6,500 kilogram vehicle to a 40 kilowatt hydrogen-air fuel cell bus. A number of 12-passenger vehicles are being operated in Moscow with this technology on a hybrid basis with gasoline and a number of exclusively hydrogen powered vehicles, including taxis, are being demonstrated on the streets of Moscow and Kharkov. Elsewhere in Europe several municipal governments are considering conversion of bus fleets to hydrogen.

Perhaps the most startling development in the hydrogen field is the contemplated $500 million hydrogen energy project under consideration by the Province of Quebec in association with the European Economic Community. This would involve the construction of a liquid hydrogen plant in the 100 megawatt range on the St. Lawrence Seaway with its output shipped to Europe in either liquid cryogenic form as ammonia or a form of liquid hydride as in the case of the Mercedes-Benz vehicle. There it would be used as fuel for transport, for testing advanced aerospace engines and for district heating purposes. Shipments would be made aboard a 20,000 ton gas tanker yet to be built but designed for at least 15 round trips a year. There is great interest in this undertaking among West German industrialists who forsee hydrogen fuels rapidly becoming cost competitive with fossil fuels as the cost of pollution becomes fully reflected in the price of energy.

Against this background, S. 639 represents a modest proposal but an essential one if the fragmented work in hydrogen on the part of the federal government is to be pulled together in an organized fashion. It calls for two 5-year development programs: one of $55 million for research and development in hydrogen production and use and the other of $100 million for hydrogen fueled aircraft R&D. This legislation reflects recommendations made by the National

Academy of Sciences, the General Accounting Office and the Department of Energy over the last ten years. I have been advocating this legislation since the 97th Congress and its cogency becomes more apparent with each passing year. I was gratified to have had as an ally throughout his tenure in this body, Senator Dan Evans of Washington, a former member of this committee, and one of the very few engineers ever to have served in the Senate. In this Congress I have gained support and co-sponsorship from Senators Wirth, Pell, Lieberman, and Boschwitz, as well as my Hawaii colleague, Senator Inouye. A companion bill, H. R. 2793, has been offered in the House by Congressman George Brown, Jr. of California.

While hydrogen has definite environmental advantages over fossil fuels, because the product of hydrogen combustion with air is essentially water vapor, it also offers benefits in the utilization of numerous energy alternatives -- ranging from coal and natural gas, to nuclear as well as to solar and the renewables. Injected into declining natural gas fields, hydrogen can serve as an enhancer, stretching out the life of dwindling supplies.

For those concerned with the interests of the coal industry, hydrogen also figures in an attractive scenario. If coal-gas reactors were to be built at the seashore, they could eject carbon dioxide into the sea instead of into the air, and transmit energy in the form of hydrogen from coal. It is claimed that this could give us perhaps another half century of coal availability without adding anything to the world greenhouse effect.

For those interested in advancing nuclear power, hydrogen can be seen as a vehicle for hurdling the safety barrier. Because energy is cheap to transport long distances with hydrogen as the storage medium and after 300 to 400 miles, increasingly cheaper than to transmit through electric wires, nuclear reactors could be located at greater distances from population areas, even mounted on sea-borne rigs.

Hydrogen's appeal to solar proponents is apparent since it is environmentally benign; indeed, it can act in behalf of environmental enhancement. For example, hydrogen has a key role in the process of nitrogen fixation whereby agricultural soils are replenished periodically. Also, there is the search for a replacement for the fully halogenated halocarbons used in refrigerants, solvents, and the like that have been found to be the culprit in the erosion of the ozone layer. One criteria in the search for a replacement is that it should be capable of introducing hydrogen into its chemical bond.

Furthermore, the renewables represent the most promising source for hydrogen's production in terms of energy expended in the process. Finally, hydrogen is key to assuring continuity of supply for solar power by providing a ready storage medium whether overnight or until the clouds scatter in the sky.

The case for hydrogen is overwhelming, and in the race for a hydrogen economy the rest of the world is already out of the starting gate while we in the United States are hardly pawing the ground. This technology is too important to get away from us. The United States must get serious about hydrogen research and development. S. 639 signals this intention, and I would urge speedy action on its passage on the part of this Committee. Thank you.

###

101st CONGRESS
1st Session

S. 639

To establish a hydrogen research and development program.

IN THE SENATE OF THE UNITED STATES

March 16 (legislative day, January 3), 1989

Mr. Matsunaga (for himself, Mr. Inouye, Mr. Wirth, Mr. Pell, and Mr. Lieberman) introduced the following bill; which was read twice and referred to the Committee on Energy and Natural Resources

---

A BILL

To establish a hydrogen research and development program.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

TITLE I—HYDROGEN PRODUCTION AND USE

FINDINGS AND PURPOSE

Sec. 101. (a) The Congress finds that—

(1) due to the limited quantities of naturally occurring petroleum-based fuels, viable alternative fuels and feedstocks must be developed;

(2) with a growing concern over the many environmental problems affecting the planet, priority should be given to the development of alternative fuels with

universal availability that have virtually no harmful environmental impacts;

(3) hydrogen is one of the most abundant elements in the Universe, with water, a primary source of hydrogen, covering three-fourths of the Earth;

(4) hydrogen appears promising as either an alternative or as an extender to finite fossil fuels capable of modifying their environmental impacts;

(5) hydrogen can be transported more efficiently and at less cost than electricity over long distances;

(6) renewable energy resources are potential energy sources that can be used to convert hydrogen from its naturally occurring states into high quality fuel, feedstock, and energy storage media; and

(7) it is in the national interest to accelerate efforts to develop a domestic capability to economically produce hydrogen in quantities which will make a significant contribution toward reducing the Nation's dependence on conventional fuels.

(b) The purpose of this title is to—

(1) direct the Secretary of Energy to prepare and implement a comprehensive 5-year plan and program to accelerate research and development activities leading to the realization of a domestic capability to

produce, distribute, and use hydrogen economically within the shortest time practicable;

(2) direct the Secretary of Energy to implement a technology assessment and information transfer program among the Federal agencies and aerospace, transportation, energy, and other market-driven entities; and

(3) develop renewable energy resources as primary energy sources to be used in the production of hydrogen.

COMPREHENSIVE MANAGEMENT PLAN

SEC. 102. (a) The Secretary shall prepare a comprehensive 5-year program management plan for research and development activities which shall be conducted over a period of no less than 5 years and shall be consistent with the provisions of sections 103 and 104. In the preparation of such plan, the Secretary shall consult with the Administrator of the National Aeronautics and Space Administration, the Secretary of Transportation, the Hydrogen Technical Advisory Panel established under section 106, and the heads of such other Federal agencies and such public and private organizations as he deems appropriate. Such plan shall be structured to permit the realization of a domestic hydrogen production capability within the shortest time practicable.

(b) The Secretary shall transmit the comprehensive program management plan to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Energy and Natural Resources of the Senate within 6 months after the date of the enactment of this Act. The plan shall include—

(1) the research and development priorities and goals to be achieved by the program;

(2) the program elements, management structure, and activities, including program responsibilities of individual agencies and individual institutional elements;

(3) the program strategies including technical milestones to be achieved toward specific goals during each fiscal year for all major activities and projects;

(4) the estimated costs of individual program items, including current as well as proposed funding levels for each of the 5 years of the plan for each of the participating agencies;

(5) a description of the methodology of coordination and technology transfer; and

(6) the proposed participation by industry and academia in the planning and implementation of the program.

(c) Concurrently with the submission of the President's annual budget to the Congress for each year after the year in which the comprehensive 5-year plan is initially transmitted under subsection (b), the Secretary shall transmit to the Congress a detailed description of the current comprehensive plan, setting forth appropriate modifications which may be necessary to revise the plan as well as comments on and recommendations for improvements in the comprehensive program management plan made by the Hydrogen Technical Advisory Panel established under section 106.

RESEARCH AND DEVELOPMENT

SEC. 103. (a) The Secretary shall establish, within the Department of Energy, a research and development program, consistent with the comprehensive 5-year program management plan under section 102, to ensure the development of a domestic hydrogen fuel production capability within the shortest time practicable.

(b)(1) The Secretary shall initiate research or accelerate existing research in areas which may contribute to the development of hydrogen production and use.

(2) Areas researched shall include production, liquefaction, transmission, distribution, storage, and use including use in surface transportation. Particular attention shall be given to developing an understanding and resolution of all potential problems of introducing hydrogen production and use into the marketplace.

(c) The Secretary shall give priority to those production techniques that use renewable energy resources as their primary energy source.

(d) The Secretary shall, for the purpose of performing his responsibilities pursuant to this title, solicit proposals for and evaluate any reasonable new or improved technology, a description of which is submitted to the Secretary in writing, which could lead or contribute to the development of economic hydrogen production storage and utilization technologies.

(e) The Secretary shall conduct evaluations, arrange for tests and demonstrations, and disseminate to developers information, data, and materials necessary to support efforts undertaken pursuant to this section, consistent with section 105.

DEMONSTRATIONS AND PLAN

SEC. 104. (a)(1) The Secretary shall conduct demonstrations of promising hydrogen economic technologies, preferably in self-contained locations, so that technical and nontechnical parameters can be evaluated to best determine commercial applicability of the technology.

(2) Concurrently with activities conducted pursuant to section 103, the Secretary shall conduct small-scale demonstrations of hydrogen technology at self-contained sites.

(b) The Secretary shall, in consultation with the Secretary of Transportation, the Administrator of the National Aeronautics and Space Administration, and the Hydrogen Technical Advisory Panel established under section 106, prepare a comprehensive large-scale hydrogen demonstration plan with respect to demonstrations carried out pursuant to subsection (a)(1). Such plan shall include—

(1) a description of the necessary research and development activities that must be completed before initiation of a large-scale hydrogen production and storage demonstration program;

(2) an assessment of the appropriateness of a large-scale demonstration immediately upon completion of the necessary research and development activities; and

(3) an implementation schedule with associated budget and program management resource requirements.

TECHNOLOGY TRANSFER PROGRAM

SEC. 105. (a) The Secretary shall implement a program designed to accelerate wider application of hydrogen production, storage, utilization and other technologies available in the near term as a result of aerospace experience as well as other research progress. The Secretary shall direct the program with the advice and assistance of a panel of industry, academia, government and other hydrogen-related interests with the intent to disseminate relatively near-term business and research opportunities that can lead to a long-term increase in hydrogen production, and utilization. The objective in seeking this advice is to increase participation of private industry in the demonstration of near commercial applications.

(b) The Secretary, in carrying out the program authorized by subsection (a), shall—

(1) undertake an inventory and assessment of hydrogen technologies and their commercial capability to economically produce, store or utilize hydrogen in aerospace, transportation, electric utilities, petrochemical, chemical, merchant hydrogen, and other industrial sectors; and

(2) develop a National Aeronautics Space Administration, Department of Energy, and industry information exchange program to improve technology transfer for—

(A) application of aerospace experience by industry;

(B) application of research progress by industry and aerospace;

(C) application of commercial capability of industry by aerospace; and

(D) expression of industrial needs to research organizations.

The information exchange program may consist of workshops, publications, conferences, and a data base for the use by the public and private sectors.

COORDINATION AND CONSULTATION

SEC. 106. (a) The Secretary shall have overall management responsibility for carrying out programs under this title. In carrying out such programs, the Secretary, consistent with such overall management responsibility—

(1) shall use the expertise of the National Aeronautics and Space Administration and the Department of Transportation; and

(2) may use the expertise of any other Federal agency in accordance with subsection (b) in carrying out any activities under this title, to the extent that the Secretary determines that any such agency has capabilities which would allow such agency to contribute to the purpose of this title.

(b) The Secretary may, in accordance with subsection (a), obtain the assistance of any department, agency, or instrumentality of the Executive branch of the Federal Government upon written request, on a reimbursable basis or otherwise and with the consent of such department, agency, or instrumentality. Each such request shall identify the assistance the Secretary deems necessary to carry out any duty under this title.

(c) The Secretary shall consult with the Administrator of the National Aeronautics and Space Administration, the Administrator of the Environmental Protection Agency, the

Secretary of Transportation, and the Hydrogen Technical Advisory Panel established under section 106 in carrying out his authorities pursuant to this title.

TECHNICAL PANEL

SEC. 107. (a) There is hereby established a technical panel of the Energy Research Advisory Board, to be known as the Hydrogen Technical Advisory Panel, to advise the Secretary on the programs under this title.

(b)(1) The technical panel shall be appointed by the Secretary and shall be comprised of such representatives from domestic industry, universities, professional societies, Government laboratories, financial, environmental, and other organizations as the Secretary, in consultation with the Chairman of the Energy Research Advisory Board, deems appropriate based on his assessment of the technical and other qualifications of such representatives. Appointments to the technical panel shall be made within 90 days after the enactment of this Act. The technical panel shall have a chairman, who shall be elected by the members from among their number.

(2) Members of the technical panel need not be members of the full Energy Research Advisory Board.

(c) The activities of the technical panel shall be in compliance with any laws and regulations guiding the activities of technical and fact-finding groups reporting to the Energy Research Advisory Board.

(d) The heads of the departments, agencies, and instrumentalities of the Executive branch of the Federal Government shall cooperate with the technical panel in carrying out the requirements of this section and shall furnish to the technical panel such information as the technical panel deems necessary to carry out this section.

(e) The technical panel shall review and make any necessary recommendations on the following items, among others—

(1) the implementation and conduct of programs under this title; and

(2) the economic, technological, and environmental consequences of the deployment of hydrogen production and use systems.

(f) The technical panel shall prepare and submit annually to the Energy Research Advisory Board a written report of its findings and recommendations with regards to the programs under this title. The report shall include—

(1) a summary of the technical panel's activities for the preceding year;

(2) an assessment and evaluation of the status of the programs; and

(3) comments on and recommendations for improvements in the comprehensive 5-year program management plan required under section 102.

(g) After consideration of the technical panel report and within 30 days after its receipt, the Energy Research Advisory Board shall submit the report, together with any comments which the Board deems appropriate, to the Secretary.

(h) The Secretary shall provide such staff, funds, and other support as may be necessary to enable the technical panel to carry out the functions described in this section.

DEFINITIONS

SEC. 108. As used in this title—

(1) the term "Secretary" means the Secretary of Energy; and

(2) the term "capability" means proven technical ability.

AUTHORIZATION OF APPROPRIATIONS

SEC. 109. There is hereby authorized to be appropriated to carry out the purpose of this title (in addition to any amounts made available for such purpose pursuant to other Acts)—

(1) $3,000,000 for the fiscal year beginning October 1, 1989;

(2) $7,000,000 for the fiscal year beginning October 1, 1990;

(3) $10,000,000 for the fiscal year beginning October 1, 1991;

(4) $15,000,000 for the fiscal year beginning October 1, 1992; and

(5) $20,000,000 for the fiscal year beginning October 1, 1993.

TITLE II—HYDROGEN-FUELED AIRCRAFT RESEARCH AND DEVELOPMENT

FINDINGS AND PURPOSE

SEC. 201. (a) The Congress finds that—

(1) long-term future decreases in petroleum-base fuel availability will seriously impair the operation of the world's air transport fleets;

(2) hydrogen appears to be an attractive alternative to petroleum in the long term to fuel commercial aircraft;

(3) it is therefore in the national interest to accelerate efforts to develop a domestic hydrogen-fueled supersonic and subsonic aircraft capability; and

(4) the use of liquid hydrogen as a commercial air transport fuel has sufficient long-term promise to justify a substantial research, development, and demonstration program.

(b) The purpose of this title is to—

(1) direct the Administrator of the National Aeronautics and Space Administration to prepare and implement a comprehensive 5-year plan and program for the conduct of research, development, and demonstration activities leading to the realization of a domestic

hydrogen-fueled aircraft capability within the shortest time practicable;

(2) establish as a goal broad multinational participation in the program; and

(3) provide a basis for public, industry, and certifying agency acceptance of hydrogen-fueled aircraft as a mode of commercial air transport.

COMPREHENSIVE MANAGEMENT PLAN

SEC. 202. (a) The Administrator shall prepare a comprehensive 5-year program management plan for research, development, and demonstration activities consistent with the provisions of sections 203, 204, and 205. In the preparation of such plan, the Administrator shall consult with the Secretary of Energy, the Secretary of Transportation, and the heads of such other Federal agencies and such public and private organizations as he deems appropriate. Such plan shall be structured to permit the realization of a domestic hydrogen-fueled aircraft capability within the shortest time practicable.

(b) The Administrator shall transmit the comprehensive 5-year program management plan to the Committee on Science, Space, and Technology of the House of Representatives and the Committees on Commerce, Science, and Transportation and Energy and Natural Resources of the Senate within 6 months after the date of the enactment of this Act. The plan shall include—

(1) the research and development priorities and goals to be achieved by the program;

(2) the program elements, management structure, and activities, including program responsibilities of individual agencies and individual institutional elements;

(3) the program strategies including detailed technical milestones to be achieved toward specific goals during each fiscal year for all major activities and projects;

(4) the estimated costs of individual program items, including current as well as proposed funding levels for each of the 5 years of the plan for each of the participating agencies;

(5) a description of the methodology of coordination and technology transfer; and

(6) the proposed participation by industry and academia in the planning and implementation of the program.

(c) Concurrently with the submission of the President's annual budget to the Congress for each year after the year in which the comprehensive 5-year plan is initially transmitted under subsection (b), the Administrator shall transmit to the Congress a detailed description of the current comprehensive plan, setting forth appropriate modifications which may be necessary to revise the plan as well as comments on and recommendations for improvements in the comprehensive program management plan made by the Hydrogen-Fueled Aircraft Advisory Committee established under section 207.

RESEARCH AND DEVELOPMENT

SEC. 203. (a) The Administrator shall establish, within the National Aeronautics and Space Administration, a research and development program consistent with the comprehensive 5-year program management plan under section 202 to ensure the development of a domestic hydrogen-fueled aircraft capability within the shortest time practicable.

(b) The Administrator shall initiate research or accelerate existing research in areas which may contribute to the development of a hydrogen-fueled aircraft capability.

(c) In conducting the program pursuant to this section, the Administrator shall encourage the establishment of domestic industrial capabilities to supply hydrogen-fueled aircraft systems or subsystems to the commercial marketplace.

(d) The Administrator shall, for the purpose of performing his responsibilities pursuant to this Act, solicit proposals for and evaluate any reasonable new or improved technology, a description of which is submitted to the Administrator in writing, which could lead or contribute to the development of hydrogen-fueled aircraft technology.

(e) The Administrator shall conduct evaluations, arrange for tests and demonstrations and disseminate to developers information, data, and materials necessary to support efforts undertaken pursuant to this section.

FLIGHT DEMONSTRATION

SEC. 204. (a) Concurrent with the activities carried out pursuant to section 203, the Administrator shall, in consultation with the Secretary of Transportation, the Secretary of Energy, and the Hydrogen-Fueled Aircraft Advisory Committee established under section 207, prepare a comprehensive flight demonstration plan, the implementation of which shall provide confirmation of the technical feasibility, economic viability, and safety of liquid hydrogen as a fuel for commercial transport aircraft. The comprehensive flight plan shall include—

(1) a description of the necessary research and development activities that must be completed before initiation of a flight demonstration program;

(2) the selection of a domestic site where demonstration activities can lead to early commercialization of the concept;

(3) an assessment of a preliminary flight demonstration to occur concurrently with the later stages of research and development activities; and

(4) an implementation schedule with associated budget and program management resource requirements.

(b) The Administrator shall transmit such comprehensive flight demonstration plan to the Congress within 2 years after the date of the enactment of this Act.

HYDROGEN PRODUCTION AND GROUND FACILITIES

SEC. 205. (a) The Administrator, in consultation with the Secretary of Transportation and the Secretary of Energy, shall define the systems, subsystems, or components associated with the production, transportation, storage, and handling of liquid hydrogen that are specifically required for and unique to the use of such fuel for commercial aircraft application.

(b) The Administrator shall structure the research and development program pursuant to section 203 to allow the development of the systems, subsystems, or components defined pursuant to subsection (a) of this section.

(c) The research and development program for hydrogen production, transportation, and storage systems, subsystems, and components which are suitable for inclusion as part of a fully integrated hydrogen-fueled aircraft system, but which are not being specifically developed for such application shall be the responsibility of the Secretary of Energy. Such activities shall be included as part of the program established pursuant to title I of this Act, and shall be so conducted as to ensure compliance with hydrogen-fueled aircraft system constraints.

COORDINATION AND CONSULTATION

SEC. 206. (a) The Administrator shall have overall management responsibility for carrying out the program under this title. In carrying out such program, the Administrator, consistent with such overall management responsibility—

(1) shall utilize the expertise of the Departments of Transportation and Energy to the extent deemed appropriate by the Administrator, and

(2) may utilize the expertise of any other Federal agency in accordance with subsection (b) in carrying out any activities under this title, to the extent that the Administrator determines that any such agency has capabilities which would allow such agency to contribute to the purposes of this title.

(b) The Administrator may, in accordance with subsection (a), obtain the assistance of any department, agency, or instrumentality of the Executive branch of the Federal Government upon written request, on a reimbursable basis or otherwise and with the consent of such department, agency, or instrumentality. Each such request shall identify the assistance the Administrator deems necessary to carry out any duty under this title.

(c) The Administrator shall consult with the Secretary of Energy, the Administrator of the Environmental Protection Agency, the Secretary of Transportation, and the Hydrogen-Fueled Aircraft Advisory Committee established under section 207 in carrying out his authorities pursuant to this title.

ADVISORY COMMITTEE

SEC. 207. (a) there is hereby established a Hydrogen-Fueled Aircraft Advisory Committee, which shall advise the Administrator on the program under this title.

(b) The Committee shall be appointed by the Administrator and shall be comprised of at least 7 members from industrial, academic, financial, environmental, and legal organizations and such other entities as the Administrator deems appropriate. Appointments to the Committee shall be made within 90 days after the enactment of this Act. The Committee shall have a chairman, who shall be elected by the members from among their number.

(c) the heads of the departments, agencies, and instrumentalities of the Executive branch of the Federal Government shall cooperate with the Committee in carrying out the requirements of this section and shall furnish to the Committee such information as the Committee deems necessary to carry out this section.

(d) The Committee shall meet at least 4 times annually, notwithstanding subsections (e) and (f) of section 10 of Public Law 92-463.

(e) The Committee shall review and make any necessary recommendations on the following items, among others—

(1) the implementation and conduct of the program under this title; and

(2) the economic, technological, and environmental consequences of developing a hydrogen-fueled aircraft capability.

(f) The Committee shall prepare and submit annually to the Administrator a written report of its findings and recommendations with regard to the program under this title. The report shall include—

(1) a summary of the Committee's activities for the preceding year;

(2) an assessment and evaluation of the status of the program; and

(3) comments on and recommendations for improvements in the comprehensive 5-year program management plan required under section 202.

(g) The Administrator shall provide such staff, funds, and other support as may be necessary to enable the Committee to carry out the functions described in this section.

DEFINITIONS

Sec. 208. As used in this title—

(1) the term "Administrator" means the Administrator of the National Aeronautics and Space Administration;

(2) the term "capability" means proven technical ability; and

(3) the term "certifying agency" means any government entity with direct responsibility for assuring public safety in the operation of the air transport system.

AUTHORIZATION OF APPROPRIATIONS

SEC. 209. There is hereby authorized to be appropriated to carry out the purpose of this title—

(1) $10,000,000 for the fiscal year beginning October 1, 1989;

(2) $15,000,000 for the fiscal year beginning October 1, 1990;

(3) $20,000,000 for the fiscal year beginning October 1, 1991;

(4) $25,000,000 for the fiscal year beginning October 1, 1992; and

(5) $30,000,000 for the fiscal year beginning October 1, 1993.

○

Senator Ford. I look forward to the testimony of the distinguished witnesses this morning. We will have three panels of two members each. The first panel will consist of J. Michael Davis, Assistant Secretary, Conservation and Renewable Energy, and Greg Reck, Director, Office of Power and Energy. If those two gentlemen will come forward, we will be glad to start with your testimony this morning.

Mr. Davis, if you would like to proceed, your statement will be included in the record. If you would like to highlight it, why that would be acceptable to the chairman of this particular hearing.

STATEMENT OF HON. J. MICHAEL DAVIS, ASSISTANT SECRETARY, CONSERVATION AND RENEWABLE ENERGY, DEPARTMENT OF ENERGY

Mr. Davis. Thank you, Mr. Chairman. I will highlight my statement for the record.

I am pleased to be here to review the Department of Energy programs for hydrogen and to comment on Title I of S. 639, the "Hydrogen Research and Development Act."

First let me make clear that hydrogen is practically nonexistent in its free state. It must be manufactured at an energy and economic cost and then distributed to the user. In this sense, it is much like electricity—that is, it is a carrier of energy which needs to be transported to the end user.

Second, the principal attraction of hydrogen is the small environmental impact of its use. However, without a production system that is equally environmentally benign, the attraction is lost. For example, 96 percent of the hydrogen used today is made from natural gas. One and one-half units of natural gas energy are necessary to make one unit of hydrogen energy, and, for every ton of hydrogen, eight tons of carbon dioxide, the major greenhouse gas, are released.

For electrolysis of water, the figures are even worse. Five units of energy are needed to make one unit of hydrogen, and 36 tons of carbon dioxide are released, with lesser amounts of acid gases such as sulfur and nitrogen oxides. Clearly, then, a renewable source of energy to produce hydrogen is necessary to achieve the environmental benefits associated with hydrogen.

Now let me turn to the bill. I will only comment on Title I and defer any comments on Title II to my colleague from NASA.

S. 639 includes many activities already being undertaken by the Department. Considerable progress has been made in understanding just what is needed for hydrogen to be an alternative energy carrier in the future. Research is continuing to find improvements in producing, storing and transporting hydrogen for transportation uses, process heating, fuel cells, and other applications.

The Department is planning its hydrogen work through the Hydrogen Energy Coordinating Committee. Peer reviews of the program are being held on a regular basis and being expanded to include more recent Congressionally mandated efforts. This peer review will further strengthen the program's research planning goals and objectives and increase inputs from industry.

Finally, DOE, at the direction of the President, is preparing a national energy strategy. The NES is designed to establish priorities for future energy research and will provide a framework for future hydrogen research planning.

With regard to specific provisions of the bill, section 102 requires the development of a comprehensive management plan. I am pleased to note that the Conservation and Renewable Energy hydrogen program is preparing a renewable hydrogen plan at this time.

Section 103 directs the Secretary to establish a research and development program. This provision is unnecessary due to the fact that DOE already manages a balanced hydrogen research and development program both at the basic and applied levels of research under existing authority.

Section 104 calls for planning and conducting small-scale demonstrations at self-contained locations. DOE opposes this provision because we believe it is premature. Technology development has not yet reached the stage where demonstration programs are technically feasible or justified. I would note that it would be an excellent situation if we had the production technology to the point where demonstrations were consistent with what we know about how to produce it.

Section 105 requires the Secretary to implement a technology transfer plan. This provision duplicates ongoing efforts. The Department currently has in place technology transfer mechanisms and intends to incorporate this type of activity as an integral part of the hydrogen research management plan.

Section 106 concerns coordination and consultation. The Department agrees that the overall management responsibility for hydrogen supply, transmission, and storage technologies should be in DOE. Occasional meetings are held informally with NASA to ensure the integration of our programs in light of their primary mission for developing aeronautics and space technology.

Other Federal agencies, such as DOD, are contacted to determine interest, information and requirements. In addition, DOE is an active participant in International Agency Agreements which deal with hydrogen. Through this mechanism, international research results are integrated into the DOE program.

Section 107 establishes a technical panel within the Energy Research Advisory Board specifically to address hydrogen on a continuing basis. The Department opposes this provision, as it gives special treatment to one fuel form over others. The Energy Research Advisory Board was a permanent panel established to provide advice to the Secretary and is being replaced by the Secretary of Energy Advisory Board.

The SEAB is intended to provide the Secretary of Energy with balanced and objective advice on all fuels and technologies. Generally, committees of this nature are formed to address specific subjects and to disband after completion of the task assigned. However, this section would provide for a special permanent panel, which would more than likely turn into an advocacy group for a particular technology, and the independence of the Secretary of Energy Advisory Board would be lost.

The Department opposes section 109 because it precludes the Secretary's and the President's ability to establish budget priorities. The planning activities being undertaken under the National Energy Strategy should be completed so that hydrogen is considered within an overall energy framework, as you alluded to in your opening remarks.

The Department has requested and expects to continue requesting funding for a hydrogen program that is appropriately balanced in the context of energy development priorities and fiscal constraints.

In conclusion, the Department agrees that hydrogen may offer strategic and environmental advantages as an energy carrier. However, investments in hydrogen R&D should be tempered by the need to evaluate the advantages and disadvantages of all potential energy resources and markets, and to develop a strategy that provides the nation with a cost-effective mix of energy supplies.

We support a balanced hydrogen R&D program. We believe the Department is already managing such a program and that it is premature to support several of the activities envisioned in S. 639. Further progress on the most immediate priority, mainly solving technology problems associated with hydrogen production, is necessary before expanding our focus to other activities envisioned by S. 639.

In summary, the Department believes the bill's general objectives are consistent with the Department's current program. But the legislation in Title I is premature.

This completes my prepared remarks. I would be pleased to answer any questions.

[The prepared statement of Mr. Davis follows, the report "Annual Report—Summary of DOE Hydrogen Programs for FY 1989" DOE/CE-0280 has been retained in subcommittee files:]

Statement of J. Michael Davis

Assistant Secretary

Conservation and Renewable Energy

U.S. Department of Energy

before the

Subcommittee on Energy Research and Development

Committee on Energy and Natural Resources

U.S. Senate

March 30, 1990

Mr. Chairman and Members of the Committee:

I am pleased to appear before the Committee to review the Department of Energy programs for hydrogen and to discuss Title I of S. 639, the "Hydrogen Research and Development Act." We defer to NASA for comments on Title II.

The Department recognizes the potential offered by hydrogen to serve as an energy transport medium and, when produced using alternate energy sources, to reduce our dependence on conventional fuels. The Department also recognizes that the production of hydrogen is energy intensive and that no net environmental or cost benefits can be expected in the near term, if, as is currently the case, hydrogen is produced using energy derived from fossil fuels.

BACKGROUND

Hydrogen is not a primary energy source -- it must be manufactured. Practically all the hydrogen now produced in this country is manufactured from natural gas. The current costs to produce and store hydrogen are $6-10/mmBtu and, depending on the method, more than $5/mmBtu, respectively. Where high purity is required or the market is small, water electrolysis is the preferred production system and production costs are higher. Electrolytic hydrogen costs $15-25/mmBtu. To provide a comparison to the current transportation fuel of choice, hydrogen, at a wholesale cost of $10 per mmBtu, is roughly equivalent to gasoline at $2.00 per gallon. Today, gasoline costs $0.56 per gallon at a Gulf Coast refinery gate.

Although some growth in specialty markets is expected, the major future growth of the hydrogen market could be as a common energy carrier, much like electricity today. Some studies indicate that hydrogen may be cheaper to transport than electricity when the distance from source to market exceeds 600 miles. In addition, certain markets will use hydrogen because of its unique properties. For example, the aerospace industry would find hydrogen attractive because of its light weight. However, for the potential of hydrogen to be realized, research and development of new or improved production, storage, transportation and utilization technologies must be successful. DOE believes that of these four areas, production is the early critical need. Based on earlier research, some sense of the technology constraints relating to storage and transportation issues is in hand.

A large measure of the attraction of hydrogen as a fuel is in the environmental benefits of its use. The combustion of pure hydrogen with air produces mostly water, with very low levels of NOx. Thus no greenhouse gas, acid gas or smog is produced as a function of the point of end use. However, when the full fuel cycle is considered, these advantages disappear in virtually all instances where hydrogen is produced from a fossil fuel source. Evaluating energy and environmental considerations over the entire fuel cycle is especially important in the case of hydrogen, where 4 to 15 units of energy input are required to produce 1 unit of energy output. No significant efficiency improvements to hydrogen production by steam reforming of natural gas are expected. Thus the availability of economical renewable energy resources will have a large bearing on the ability to realize any of hydrogen's advantages.

DOE R&D PROGRAM OVERVIEW

DOE supports a variety of hydrogen-related research activities. The Office of Conservation and Renewable Energy sponsors applied research aimed at establishing hydrogen as a viable link between renewable primary resources and energy demand sectors. The Office of Energy Research conducts basic research, such as understanding the interactions between hydrogen and metals, which are important to fossil, civilian nuclear and defense applications and to renewable hydrogen storage and transportation. Hydrogen-caused embrittlement, an increasing problem in civilian nuclear reactors, would significantly affect the tanks and pipelines of an extensive distribution system. Other DOE Programs including Fossil Energy, Fusion Energy, Inertial Fusion, and Defense Programs also support research related to hydrogen. An overview of their efforts is included in the attached report.

To insure that the many facets of DOE's hydrogen programs are coordinated, the Hydrogen Energy Coordinating Committee (HECC) was established 10 years ago. Every year, HECC brings together the various researchers within the Department for the purpose of coordinating activities and discussing research results and future direction. I have attached, for the record, a copy of the most recent HECC "Annual Report--Summary of DOE Hydrogen Programs for FY 1989." This document is also used as a technology transfer medium to provide information to the research community and the public. Other Federal agencies such as NASA and DOD are contacted to determine interests, information and requirements. In addition, DOE is an active participant in an International Energy Agency agreement that deals with hydrogen. Through this mechanism, international research results are integrated into the DOE program.

The DOE Office of Energy Research supports long-range hydrogen-related research in the divisions of Chemical Sciences, Materials Sciences, and Energy Biosciences. The Chemical Sciences research focuses on the fundamental understanding of the chemistry involved in production and storage concepts at the most basic level. In solar photochemistry, fundamental processes are being explored which can be applied to split the water molecule to produce hydrogen, to produce methanol from carbon dioxide, to synthesize ammonia from atmospheric nitrogen, or to produce other chemicals at lower energy cost. The research is expected to provide the basis for new solar chemical technologies in the distant future. Materials Sciences programs related to hydrogen are focused on obtaining a fundamental understanding of the interactions of hydrogen with materials.

The Division of Energy Biosciences in the Office of Energy Research supports research aimed at understanding the mechanisms involved in the biological production and utilization of molecular hydrogen. The long-term objective of the program is to provide the requisite scientific foundation for the development of novel biotechnologies based on hydrogen as an energy resource or ones in which hydrogen plays an integral role in the production of other products such as methane. The emphasis of the research supported is on the bioenergetics of hydrogen production and the enzymes, the hydrogenases, responsible for the production of hydrogen, driven by light energy directly or indirectly through renewable plant resources. These programs are basic or generic in character and do not directly engage in the development of specific technologies for a hydrogen economy. They do, however, provide fundamental understanding necessary for the development of these and other related technologies; for example, technologies related to hydrogen storage, end-use, and synfuel production.

In the Office of Conservation and Renewable Energy, ongoing R&D activities are pursuing potential efficiencies in renewable resource conversion processes to make possible the production of economical hydrogen with minimal use of fossil resources. The program also addresses hydrogen storage and transportation.

The steam reforming of natural gas to manufacture hydrogen leads to carbon dioxide and carbon monoxide emissions and consumes a valuable conventional fuel. Therefore, the renewable hydrogen production program is focused on the dissociation of water. Energy used for dissociating water can be in the form of heat or electricity. Since thermodynamic limitations of steam cycles used to produce electricity imply an efficiency ceiling, the direct utilization of heat in water-splitting processes has been explored. Substantial earlier efforts directed toward thermal decomposition processes operating in extreme temperature regimes (greater than 3000° C) indicate that materials handling, corrosion, and process complexity are problems which do not have apparent solutions.

The combination of thermal and electrochemical processes can be optimized via the development of high-temperature (300°C-1000°C) water vapor dissociation. For such systems, overall energy efficiencies approaching 35 percent are possible, compared to the 27 percent efficiency typical of conventional electrolysis. Based on prior results, research in this area focuses on intermediate-temperature (300 to 500° C) processes.

Other hydrogen production research efforts focus on solar-driven production systems. For example, triple-stacked photocell units that are much like Polaroid film can use sunlight to split water into hydrogen and oxygen. This system incorporates active, organic layers which contain photosensitive dyes similar to those used in color photography. The long-term goal is to develop a light-stable, triple-layer structure that is sensitive to blue, green and red photons to capture the maximum solar energy possible. In effect, this technology uses a photovoltaic conversion process to produce the electricity needed for electrolysis, thereby extracting hydrogen from water in a single step. Partially in support of this research, other fundamental research is developing the means to attach and, equally importantly, to remove spent biological films on conductive polymer substrates. Attempts are being made, in collaboration with researchers in England and Switzerland, to stabilize these materials.

Current hydrogen storage practice relies on compressed gas or liquefied hydrogen as the primary options. These storage systems do not lend themselves to the bulk long-term or mobile short-term applications that would be necessary for hydrogen to assume an expanded role in supplying future U.S. energy needs. Since mobile storage is the more serious problem, our current research effort is focused on using surface-modified activated carbon as the storage medium. The system is expected to be capable of storing hydrogen at 4% by weight (twice current technology) at -123° Centigrade and 15 times atmospheric pressure. The goals have been achieved in the laboratory, and a larger engineering-scale system is in development to confirm the results.

The widespread use of hydrogen as a gas would require a handling, distribution, and dispensing system that, particularly for highway transportation, would require a fundamental change in the current method of fuel replenishment. One option being explored as part of the liquid biofuels program is to use hydrogen to enhance the production of methanol and then distribute the methanol through an upgraded liquid fuel pipeline. This would mitigate the distribution and end use problems and make more of the carbon in biomass available as fuel.

The development of this methanol option for liquid transportation fuel replacement is the near-term goal of the hydrogen program (i.e., technology available by 1995). To support this goal, hydrogen will have to be available from renewable energy sources at the same cost required to extract it from natural gas, i.e. $10 per mmBtu. The long-term goal is to provide hydrogen as a transportation fuel alternative when shortages in conventional fuels result in dramatic price increases. In addition to a price of $10 per mmBtu ($2.00 wholesale price per gallon of gasoline), storage at $1-3 per mmBtu will be essential, and a new distribution system must be developed.

The final element in the transition to hydrogen would be to optimize the end-use equipment and particularly engines. However, without successful resolution of the problems associated with production, storage and transportation, end-use applications will not be needed and, therefore, they are explored as the last priority.

S. 639

Now let me turn to specific comments on S. 639, "The Hydrogen Research and Development Act." As I noted, I will confine my comments to Title I.

S. 639 includes many activities already being undertaken by the Department. Considerable progress has been made in understanding just what is needed for hydrogen to be an alternative energy carrier in the future. Research is continuing to find improvements in producing, storing, and transporting hydrogen for transportation, process heating, fuel cells, and other applications.

The Department is planning its hydrogen work through the HECC. Peer reviews of the program are being held on a regular basis and being expanded to include more recent congressionally mandated efforts. This peer review will further strengthen the program's research planning, goals and objectives and increase inputs from industry. Finally, DOE, at the direction of the President, is preparing a National Energy Strategy (NES). The NES is designed to establish priorities for future energy research and will provide a framework for future hydrogen research planning.

With regard to specific provisions of the bill: Section 102 requires the development of a comprehensive management plan. I am pleased to note that the Conservation and Renewable Energy Hydrogen Program is preparing a renewable hydrogen plan at this time.

Section 103 directs the Secretary to establish a research and development program. This provision is unnecessary because DOE already manages a balanced hydrogen research and development program both at the basic and applied levels of research under existing authorities.

Section 104 calls for planning and conducting small-scale demonstrations at self-contained locations. DOE opposes this provision as premature.

Technology development has not yet reached the stage where demonstration programs are technically feasible or justified.

Section 105 requires the Secretary to implement a technology transfer plan. This provision unnecessarily duplicates on-going efforts. The Department currently has in place technology transfer mechanisms, and intends to incorporate this type of activity as an integral part of the hydrogen research management plan.

Section 106 concerns coordination and consultation. The Department agrees that the overall management responsibility for a hydrogen supply, transmission and storage technology should be in DOE. Occasional meetings are held informally with NASA, to insure the integration of our programs in light of their primary mission for developing aeronautics and space technology. Other Federal agencies such as DOD are contacted to determine interests, information and requirements. In addition, DOE is an active participant in an International Agency agreement that deals with hydrogen. Through this mechanism, international research results are integrated into the DOE program.

Section 107 establishes a technical panel within the Energy Research Advisory Board (ERAB) specifically to address hydrogen on a continuing basis. The Department opposes this provision, as it gives special treatment to one fuel form over others. ERAB was a permanent panel established to provide advice to the Secretary, and it is being replaced by the Secretary of Energy Advisory Board (SEAB). The SEAB is intended to provide the Secretary of Energy with balanced and objective advice on all fuels and technologies. Generally, committees of this nature are formed to address specific subjects and to disband after completion of the task assigned. However, this section would provide for a special permanent panel, which would more than likely turn into a special advocacy group for a particular technology, and the independence of the SEAB would be lost.

The Department opposes Section 109 because it precludes the Secretary's and the President's ability to establish budgetary priorities. The planning activities being undertaken under the NES should be completed so that hydrogen is considered within an overall energy framework, prior to authorizations of particular federal expenditures. The Department has requested and expects to continue to request funding for a hydrogen program that is appropriately balanced in the context of energy development priorities and fiscal constraints.

CONCLUSION

The Department agrees that hydrogen may offer strategic and environmental advantages as an energy carrier. However, investments in hydrogen R&D should be tempered by the need to evaluate the advantages and disadvantages of all potential energy resources and markets, and to develop a strategy that provides the nation with a cost-effective mix of energy supplies.

We support a balanced hydrogen R&D program. We believe the Department is already managing such a program and that it is premature to support most of the activities envisioned in S. 639. The bill seeks to do too much too soon, rather than focusing on the most immediate priorities -- mainly, solving technological problems associated with hydrogen production. In summary, the

Department believes that the bill's general objectives are consistent with the Department's current program, but the legislation is unnecessary and in some ways counterproductive. Accordingly, we oppose enactment of Title I of S.639.

This completes my prepared remarks. I would be pleased to respond to the Committee's questions at this time.

Senator **Ford**. Thank you very much, Mr. Davis.

Mr. Reck, would you proceed, and then we will have some questions for both of you.

STATEMENT OF GREGORY M. RECK, DIRECTOR, PROPULSION, POWER AND ENERGY DIVISION, OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. **Reck**. Thank you, Mr. Chairman. I would also like to make my written testimony a part of the record and just summarize.

Senator **Ford**. Your total statement will be included in the record.

Mr. **Reck**. Thank you.

I am pleased to be here to describe NASA's programs in hydrogen research and to discuss with you our assessment of Title II of S. 639, the Hydrogen Research and Development Act.

For many years now NASA has been fully cognizant of the potential benefits inherent in the use of hydrogen for aerospace applications. NASA has conducted and will continue research on hydrogen and related technologies when it is the correct fuel of choice for the application. We use hydrogen extensively in hypersonic flight research and in the aerospace plane program to enable orbit capability. Hydrogen will continue to be an essential part of our space propulsion and power programs.

However, we believe that the current and projected cost of hydrogen does not support Title II's objectives of accelerating efforts to develop and demonstrate a domestic hydrogen-fueled commercial aircraft capability.

Two years ago I testified to this Subcommittee and described the research that NASA had conducted on hydrogen for a variety of NASA missions since the 1950s. In that decade, in the 1950s, we demonstrated the feasibility of liquid hydrogen as an aircraft fuel by flying a B-57 aircraft with one engine modified to burn hydrogen.

The results of that demonstration, combined with our subsequent years of ground-based research, have shown that there are no major technical issues associated with burning hydrogen in aircraft turbine engines in flight.

In the late 1970s, NASA, working with the aircraft industry, performed assessments on the overall prospects for liquid hydrogen as a fuel for commercial subsonic jet aircraft. These assessments addressed fuel containment, fuel systems, performance potential, airport infrastructure, and overall safety aspects and fuel production efficiency and economics.

The most significant findings are described in my written testimony, and although technical issues surfaced, the pacing item identified for hydrogen fuel was hydrogen production cost. As a result, hydrogen technology development for subsonic aircraft was put on hold by NASA until future production economics changed sufficiently to warrant a resurgence of these activities.

However, the National Aerospace Plane Program, or NASP, represents one area where key technology efforts addressing hydrogen to power future aircraft have been reactivated. The NASP program, which is jointly sponsored by NASA and the Department of Defense, is developing technologies for a single stage to orbit vehicle which would take off and land horizontally as a conventional aircraft, and use air-breathing engines to accelerate to hypersonic speeds in the atmosphere.

In the case of NASP, performance and not fuel production economics is the justification for hydrogen as the fuel of choice. The high energy density, ease of combustion, and cryogenic qualities of hydrogen are enabling to the goal of single stage to orbit.

Many of the technologies being pursued in the NASP program will provide significant benefits to on-board storage and delivery of hydrogen for transport aircraft in general. Specific area of current focus research include slush hydrogen, hydrogen materials compatibility, lightweight fuel tanks, and hydrogen mixing and combustion and high speed air flows.

A substantial design problem with hydrogen-fueled aircraft is the large fuel volume requirements. Slush hydrogen, a mixture of solid and liquid hydrogen, would improve the situation because of increased density and reduced volume. Hydrogen also interacts adversely with some of the materials that we use in construction of tanks, fuel lines and pumps, and it can cause embrittlement and loss of component life.

In the NASP program we are conducting research on new alloys, such as titanium aluminides, which may be more resistant to this phenomenon than conventional titanium alloys. We are also looking at hydrogen-resistant coatings, and as the properties of these materials and coatings are developed they are being fed into design studies for new, innovative tank concepts.

If a decision is made in several years to proceed to the flight demonstration phase of the NASP program, all of the design and development issues associated with using hydrogen fuel in an aircraft-type vehicle will be addressed. These activities will provide many of the technological improvements needed for hydrogen-fueled commercial transport aircraft in the future.

In addition to hydrogen research for NASP, NASA is continuing research activities for improved hydrogen-oxygen rocket propulsion systems. Specific developments which will be applicable to future aircraft include cryogenic fuel pumps, bearings lubricated by hydrogen, seals and flow sensors that operate in the cryogenic environment.

The advanced launch system program, jointly supported by NASA and the Air Force to provide a low-cost launch capability, has identified hydrogen as the likely fuel for both the main and booster engines on this family of vehicles. Currently, advanced development activities are under way to develop robust, low-cost fuel pumps and other components for this program.

Finally, we have been studying the need for a liquid hydrogen structural test facility which would be capable of simultaneous simulation of thermal and mechanical loads to the structure in hydrogen tanks.

In summary, for commercial aircraft application we continue to believe that the economic aspects of commercial production, liquefaction, storage, and handling are the pressing issues to be addressed to provide hydrogen as a viable fuel option for the future.

We feel confident that when the economic issues associated with supply are solved NASA will have resolved a number of the vehicle system technical issues through related hydrogen research both in the NASP program and in our space programs.

At that time, we could reestablish the appropriate efforts on any remaining issues for commercial aircraft application.

Concerning the provisions of S. 639, we believe it is premature, as a consequence of what I related, to establish a separate program and associate advisory committee directed at hydrogen-fueled aircraft and flight demonstrations beyond that currently planned for the NASP program. NASA will remain cognizant of the technical needs associated with hydrogen- fueled flight vehicles and continue to provide the application-related technology advances through our research and development programs.

However, this technology and its projected advances are considered ahead of both the current and projected economic feasibility of hydrogen fuel production.

This completes my summary, and I would be happy to respond to any questions.

[The prepared statement of Mr. Reck follows:]

STATEMENT

OF

Mr. Gregory M. Reck
Director, Propulsion, Power and Energy Division
Office of Aeronautics, Exploration and Technology

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

before the

Subcommittee on Energy Research and Development
and the
Committee on Energy and Natural Resources
United States Senate

Mr. Chairman and Members of the Subcommittee:

I am pleased to appear before you today to discuss with you NASA's hydrogen research efforts and S. 639, a bill to establish a Hydrogen Research and Development program. NASA opposes enactment of this bill for the reasons discussed below.

For many years now, this agency has been fully cognizant of the potential benefits inherent in hydrogen use for aerospace propulsion and energy storage. We have continuing research efforts which began in the 1950's related to the utilization of hydrogen applicable to a variety of NASA missions. When we testified to the Subcommittee on Energy Research and Development in September 1987, we included details of both our past, as well as active, research efforts in hydrogen. I would like to take the opportunity today to briefly recap the major points of that testimony and update you on our hydrogen research activities over the past three years, particularly that of the National Aero-Space Plane (NASP) program. I will also explain why NASA views the objectives of Title II of the bill, which directs a research, development and demonstration program for a domestic hydrogen-fueled aircraft capability, as premature at this time.

From a historical perspective, the National Advisory Committee for Aeronautics (NACA) investigated and successfully demonstrated the feasibility of liquid hydrogen as an aircraft fuel in the mid-to-late 1950's. This was accomplished by flying a B-57 with one engine modified to burn hydrogen fuel during cruise. The hydrogen system addition included a stainless steel wing-tip liquid hydrogen tank, a ram air heat exchanger to vaporize the liquid hydrogen, and a regulator to control the flow of fuel to the engine. The J-65 turbojet engine was minimally modified by the addition of a hydrogen manifold and injection tubes. The aircraft utilized conventional military kerosene (JP-4) to power both engines for takeoff and climb to cruise altitude where one engine was then switched to hydrogen. Several flights were accomplished, with hydrogen operation occurring for approximately 20 minutes per flight. The results of this demonstration combined with considerable ground-based research over the years have shown that there are no major technical issues associated with burning hydrogen in aircraft gas turbine engines.

Based on this successful demonstration, NASA performed an assessment from 1974 through 1980 of the overall prospects for liquid hydrogen as a fuel for commercial subsonic jet aircraft. The program included several contracted studies by U.S. industry, and addressed aircraft fuel containment and fuel-related subsystems, performance potential, airport infrastructure and overall safety aspects, and fuel production efficiency and economics. The most significant findings of the assessment follow:

Fuel Containment and Subsystems - The cryogenic hydrogen for the study aircraft was stored in insulated tanks located fore and aft of the passenger compartment since the low density of liquid hydrogen makes it impractical to house it within the aircraft wing as is the current practice with kerosene fuels. Several cryogenic insulation schemes were evaluated with two attractive candidates identified: a two-layer external closed-cell foam insulation; and a microsphere system, along with concepts for pumps, lines, and purge systems. A number of subsystem studies were conducted to give depth to the fuel system analyses, including selection of preferred materials and foam insulation systems for liquid hydrogen tanks based on both analytical and experimental efforts.

Performance Potential - The only noteworthy advantage of hydrogen-fueled aircraft, based on this design approach over kerosene-fueled aircraft, was in large-capacity (400 passengers), long-range (5500 nautical miles) applications.

Airport Infrastructure and Overall Safety Aspects - The preferred concept for hydrogen handling included delivery of hydrogen gas to the airport, a liquefaction plant and storage facilities at the airport, and a closed-loop liquid hydrogen circulation system to deliver the fuel to the aircraft. There were no technical problems associated with such airport facilities which did not lend themselves to straightforward engineering solutions. The safety assessment identified potential positive safety aspects of hydrogen to include: (1) its low flame emissivity; (2) the lack of smoke in a hydrogen fire which may aid passenger egress to safety; and (3) the buoyancy of hydrogen and its fireball that may reduce the damage from an engulfing flame. Potentially negative safety aspects included: (1) its high volatility; (2) its wide flammability limits;(3 its low ignition energy requirements

requirements; and (4) the potential for detonation of a confined or partially confined hydrogen-air mixture if ignited.

Fuel Production Efficiency and Economics - Fuel production studies showed that the efficiency of producing liquid hydrogen from coal or oil shale was less than for producing liquid methane or synthetic Jet-A fuel. Associated economic studies performed in 1979 indicated that liquid hydrogen would cost roughly twice as much as synthetic Jet-A from either oil shale or coal including production, pipelining 500 miles, liquefaction, storage and distribution at the airport.

Although many technical issues were surfaced during this overall prospects assessment, the pacing item identified for hydrogen use was the basic cost of fuel production relative to other viable choices. As a result, aircraft-related technology development has been put in abeyance by NASA for the most part, until such time that evidence of fuel production economics change sufficiently to warrant resurgence of those activities.

I would now like to switch to one area where technology efforts addressing hydrogen to power future aircraft have been reactivated -- the NASP program. It is important to note that in the case of the NASP, performance and not fuel production economics is the key issue, with hydrogen being the fuel of choice because it is enabling to the goal of single-stage-to-orbit capability. Nonetheless, many of the technologies being addressed provide significant potential benefits to onboard storage and delivery for transport aircraft in general. Specific areas of focussed research now underway include slush hydrogen, hydrogen/materials compatibility, lightweight fuel tanks, and hydrogen mixing and combustion in high speed airflows.

Slush hydrogen is a mixture of solid and liquid hydrogen that offers the benefits of increased density (large fuel volume requirements remain as a substantial design problem with hydrogen-fueled aircraft), as well as increased cooling capacity. As part of the NASP program, the NASA Lewis Research Center has a government/industry program underway to characterize properties and design data for slush hydrogen and to explore pilot plant processes for large-scale production.

Hydrogen also interacts adversely with many materials used for tanks, fuel lines and pumps, leading to embrittlement and thus reduced service life. The NASP program is providing research for new alloys based on titanium aluminides, which are more resistant than conventional titanium alloys. In addition, hydrogen-resistant barrier coatings are being evaluated that incorporate multilayered protection schemes involving several layers of materials, each performing a contributing function. As the properties of these materials and coatings are developed, they are being fed into ongoing design studies for new, innovative tank concepts. Material advances and new approaches evolving from this process will offer lighter-weight, extended-life tank design options in general for future hydrogen-fueled aircraft.

In addition to hydrogen research for the NASP program, NASA is continuing hydrogen research activities for rocket propulsion applications, in particular, using a Space Shuttle main engine testbed facility. Specific technology developments offering synergy to future aircraft applications include cryogenic fuel pumps, bearings lubricated by hydrogen, seals, hydrogen flow metering and diagnostics that operate in the cryogenic environment.

Finally, we have a FY 1991 Construction of Facilities budget request for a liquid hydrogen structural test facility which will provide large scale ground testing capability for the conduct of research, design, and verification of flight worthiness of tanks and other components of liquid hydrogen-fueled vehicles for NASA and industry needs. Such a facility will simultaneously simulate thermal and mechanical structural loads which could be expected in an operational environment. The capability provided by such a facility will be required for future space transportation vehicles, transatmospheric vehicles such as the NASP, and possible derivative hypersonic cruise vehicles.

In summary I would like to reiterate and update the conclusions from our 1987 testimony. NASA has and will continue to use hydrogen when it is the correct fuel choice, including development of needed application-related technologies. We will use hydrogen extensively in hypersonic flight research and in the aerospace plane to enable orbital capability based upon airbreathing propulsion concepts. Hydrogen will also continue to be an essential part of our space propulsion and power programs. However, for commercial aircraft application, we continue to believe that the economic aspects of commercial production, liquefaction, storage, and handling are the key pacing issues that must be addressed to provide hydrogen as a viable fuel option for the future. We feel confident that when the economic issues are resolved by the appropriate parties, NASA will have resolved a number of vehicle system technical issues through the hydrogen-related work being performed in the NASP and space programs. At that time we could readily establish the appropriate efforts on any remaining issues for commercial aircraft application.

Therefore, concerning the provisions of S. 639, we believe it prudent that NASA continue to be cognizant of the technical needs associated with hydrogen-fueled flight vehicles, and continue to provide the application-related technology advances through our R&D programs. However, this technology and its projected advances are considerably ahead of both the current and projected economic feasibility of hydrogen fuel. Consequently, we believe it is premature to establish a separate program and an associated advisory committee directed at hydrogen-fueled aircraft technology and flight demonstration beyond that currently planned in the NASP program.

Thank you, Mr. Chairman. That completes my prepared statement. I would be pleased to address any questions you may have.

Senator FORD. Thank you very much, Mr. Reck.

Mr. Davis, it seems that the Department you are representing here today has had a little change of heart. Your fiscal year 1991 request for hydrogen production research is $2.5 million. Now that is an increase over the $2.4 million appropriated for this research in the 1990 budget.

Would you tell the Committee why you are asking to increase the budget, when we have for so long had a zero budget come up here and we had to put the money in?

Mr. DAVIS. Well, sir, the simple answer is maybe we are listening more carefully.

Senator FORD. I would like for you to believe the program is worth the money rather than you finally agree with us or whatever, but that you think the program is worth the money that you are spending or that we have requested you to spend.

Mr. DAVIS. It is. We think that investments in the renewable technologies to produce hydrogen have merit, and we are trying to bring forward an investment in renewable hydrogen production that also is consistent with the other technology energy supplies that we have to balance within our budget.

Senator FORD. Well, let me let you go a little bit further. What is your view of the authorization level of $4 million for hydrogen research for fiscal year 1991 enacted by Congress last year as Public Law 101-281, which we refer to as the Fowler bill? Would that be too far out?

Mr. DAVIS. No, sir, I would not say that it is. But one of the things we are really trying to accomplish throughout our whole budget is focus. And the question becomes how many different topics within a particular research program should be addressed, and in what priority.

If there was more money available, we would still focus that money on the particular topic of hydrogen production. The second priority would be dealing with storage. So we, at whatever level of funding is the final decision, are going to try to maintain a focus of activity so that we can produce results.

Senator FORD. As you mentioned, DOE supports hydrogen research under several accounts—renewable energy, basic energy sciences, fossil energy. Taking these all into account, how much is DOE proposing to spend on hydrogen research in fiscal year 1991?

Mr. DAVIS. The totals in fiscal year 1991 actually would be almost $39 million. We split that into categories that we call mission-related and non-mission-related.

The mission-related activities are those activities directed specifically at hydrogen production, storage, transmission, utilization. And that total is $3.5 million for the Department of Energy. The bulk of it, as you suggest, is the $2.5 million in renewable, and $.3 million in fossil, and $.3 million in basic energy sciences.

There is a total of $33.9 million of research related to hydrogen that we refer to as non-mission that looks at hydrogen in a molecular sense, understanding hydrogen, its reactivity, how it reacts with different metals. There is a large chunk in basic energy sciences of almost $17 million. And, of course, there is also about $10 million involved in hydrogen as it relates to weapons production.

Senator FORD. Do you do that research, or is it farmed out? How do you develop that research for the Department?

[The information follows:]

The non-mission activities are conducted at DOE laboratories and at other Federal and university laboratories. For example, the photochemical generation of hydrogen research program of the Office of Basic Energy Sciences is carried out at 4 DOE laboratories, the Notre Dame Radiation Laboratory, the National Institute of Standards and Technology, and 31 Universities. The details of all of the non-mission related research activities are listed in the Hydrogen Energy Coordinating Committee Annual Report-Summary of DOE Hydrogen Programs for 1989. No significant changes are expected in FY 1990 and FY 1991.

Mr. DAVIS. I would have to respond for the record on the nonmission-related activities, but as far as the activity within the renewable portion of the budget, that is primarily subcontracted outside the Department.

Senator FORD. Is it one of the national labs?

Mr. DAVIS. The majority of it right now is actually being conducted at four centers—Florida Solar Energy Center, University of Miami, Texas A&M University, and Hawaii National Energy Institute.

Senator FORD. I guess Public Law 101-218, or the so-called Fowler bill, requires that you show hydrogen research and development as a separate line item in future budget requests. Will you be complying with that?

Mr. DAVIS. It is my understanding that we will comply with that.

Senator FORD. Would you provide the Subcommittee with your recommended changes in S. 639 in order to gain your support for the bill? What I am trying to get is what would you agree to and see how close we might come, so that we could put this on track rather than run into a problem with the Department, OMB or whoever else.

I would like to see if we could arrive at some decision or compromise. I prefer not to call it a deal. But if you would do that I think it would be very helpful to this legislation, and we would not be getting into the you say no, Congress says yes, and Congress makes you do it because they put the money in and you do not particularly want to do it.

I do not think that helps anyone. I would like to have something that we could arrive at, some agreement or at least get close, so it would not be too far out of line. Could you do that for us and do it in a timely manner, Mr. Davis?

Mr. DAVIS. Yes, sir. I totally agree, and I will provide it as soon as possible.

[The information follows:]

My program personnel will prepare draft provisions of a bill that would be acceptable to the Administration. We expect to begin the clearance process for those provisions within the month.

Senator FORD. You are nice to do that and I appreciate your effort.

Mr. Reck, according to your testimony you believe that Title II of the bill is premature. Title II calls for research and development and a plan—I underscore "plan"—for demonstration. Why is this premature?

Mr. **Reck**. It is really based on the studies that we did and have continued, principally in the 1970s, in the late 1970s, working with the industry, the airframe manufacturers and engine companies and their subcontractors, to examine all the aspects associated with using hydrogen fuel in commercial transport aircraft.

And in those studies, although there were some efficiencies identified for long-range transport aircraft, in general the conclusion, as I indicated in my testimony, is that the very high cost of hydrogen fuel compared to conventional kerosene-based fuels really erases most of those benefits and efficiency and, until the costs of hydrogen become somewhat lower and the use of hydrogen is more economically attractive for airline users, we feel that a continued investment at this point in time would be premature.

So we feel that the focus in terms of research should be on reducing those production costs and the storage and distribution costs associated with that. When those become more in line, we feel that we can capitalize on the investments we are making in hydrogen-related technologies in other programs and use those to best develop a research and development program that would be focused on the domestic hydrogen-fueled airplane objectives of S. 639.

Senator **Ford**. Well, you are proceeding forward with your space plane. But that does not seem to bother you about cost or anything like that. You are proceeding on with that and yet you say to the others it is premature. I do not think that statement squares with me.

Mr. **Reck**. I understand the confusion. The difference is that for an aerospace plane capability hydrogen fuel is required, and although the cost of supplying the hydrogen fuel is higher than other alternatives, hydrogen fuel is the only fuel because of its high energy density, its cryogenic cooling capabilities, and its combustion properties that we can use to get there.

That is principally the reason that hydrogen fuel is used in the space shuttle, is used in the Centaur upper stage vehicle, and will likely be used in the ALS, advanced launch system vehicles. It is really required in that case.

We certainly would be appreciative of a lower price or a lower cost for hydrogen use in those vehicles, but at this point in time the selection of hydrogen is based on its properties and the fact that it is enabling for that vehicle.

Senator **Ford**. I am somewhat perplexed, I guess, that this argument would say to us we do not need a plan. What is wrong with setting out a plan that is something that you want to go for, get it down in black and white? You are arguing against a plan because you have not found a cheaper way to develop hydrogen.

All we are saying here is that you ought to have a plan. I could tell you some stories about plans, but you do not have time to listen to my funny stories. But what is wrong with just developing a plan and say this is where we want to go and these are our objectives? Just lay it out.

Yet you are saying no, because we have not found a way to produce it cheaply yet.

Mr. **Reck**. I think that one aspect is that some of the information that we are going to derive from some of the other studies that we are doing is going to enable us to do a much better job of determining what the best approach to a subsonic transport aircraft might be in the future.

So I think we are going to gain knowledge over the next several years, through the very aggressive efforts in hydrogen technologies associated with these other activities, that when it becomes economically feasible will enable us to do a better job of determining what research and development activities should be done.

I think to do that at this point, working with and in concert with the industry partners, the manufacturing companies involved in the aircraft production, we jointly feel that it, as I say, would be premature to begin to determine just what technologies would be necessary and what approaches and concepts would be best pursued to develop a hydrogen-fueled subsonic transport.

Senator FORD. Could you make it generic. I asked a lawyer one time when I was chairman of a civic organization, I said, what position should I take. He said take either one; we can make one hell of a case.

So it seems to me that you could say here is a plan without saying we want this kind of technology, we have got to do this, we have got to do that. You are doing research, and then you are making a decision after that. I think you ought to have a goal. Your goal is X. How are you going to get there?

We will get around to that. I think you are going to get it, so you might as well be prepared. It is kind of hard for me to understand why we are so slow in this, since hydrogen is widely used today in processes such as petroleum refining, chemical manufacturing, electronics, glass production, hydro-generation of fat. Research is continuing on other promising applications.

The space shuttle is the United States' largest user, and it seems to me that there ought to be a plan, that you would welcome a plan that we could help you with. You know, we are sitting here trying to develop a plan so we can have a way to go, and then we find that no, we do not want a plan. We want to go ahead and research and when we decide what to do, then we will tell you.

I am not sure that is going to fly too well here. We may have our own hydrogen plan worked out.

I have no further questions unless you have some kind of follow-up, Mr. Davis. You are smiling a little bit. Do you want to stay out of this?

Mr. DAVIS. Yes, sir. [Laughter.]

Senator FORD. Okay. We may dump you in, my friend. Thank you all very much. I appreciate it. If you have any further thoughts you would like to put into the record, we would be delighted to have them.

Mr. DAVIS. Thank you, Mr. Chairman.

Senator FORD. Thank you. The next witnesses will be Jeffrey A. Serfass and Patrick Takahashi. We had to do something, Pat, to get you to come back to Washington. We have missed your smiling face around here.

Did I pronounce your name right?

STATEMENT OF JEFFREY A. SERFASS, PRESIDENT, NATIONAL HYDROGEN ASSOCIATION

Mr. **Serfass**. Yes, sir, Senator. I was impressed.

Senator **Ford**. If you will proceed, we will put your full statement in the record and if you can highlight it for us, we would appreciate it. It is Friday and we will be going into session shortly. I would not want our testimony to be cut off.

Mr. **Serfass**. Thank you. I will be brief.

I am president of the National Hydrogen Association, and I appreciate, on behalf of the organization, your invitation to appear today. Just briefly let me state that the National Hydrogen Association was formed barely a year ago. We have 22 members and are growing at this time—industrial, research members such as Patrick Takahashi's organization, and small business members, really quite a broad cross section.

As much an indication as anything in terms of our growth, we had about 115 people here at a meeting, part of which was here at the Capitol, just a few weeks ago.

I agree with your opening comments in which you indicated that hydrogen has been around for a while as an interest. It has fluctuated up and down. I believe right now the interest in hydrogen, very appropriately, is growing.

Our mission is to develop hydrogen technologies and their utilization in industrial and commercial applications, and to promote the transition role of hydrogen in the energy field.

Let me say that I understand, as you do, that we are talking about hydrogen as a fuel. It has been used in industrial settings. What we are talking about here is expanding a relatively small percentage of its use into a major use—hydrogen as a fuel. It is our view, industry's view, that there is obviously tremendous long-term potential as an energy vector and as a fuel.

What we need, I believe, is a transition strategy. Most knowledgeable people, I think, agree that hydrogen will be the fuel sometime after the turn of the century, possibly 2020 and beyond; maybe it is a long-term effort. But hydrogen will be the clean and acceptable, superior fuel of the future.

It is abundant. It is clean, like electricity, and it is simple. We lack a strategy. We as an organization are too new to have developed a strategy. I believe the Department of Energy and those in this room, for that matter, understand that we need to develop a path to get from today's use of conventional fuels to that point in the future where hydrogen is the accepted and used fuel.

There is no doubt economics do not favor hydrogen today. The gentlemen before me are absolutely correct. The cost of hydrogen produced from other fuels, as it must be produced, prohibit its use generally in today's world as a competitor or an alternative to natural gas and coal, because that natural gas and coal will be used to produce the hydrogen.

There is no doubt that, with the high cost of electricity relative to the BTU output that would produce the hydrogen, that the cost of hydrogen through electrolysis is also very expensive.

Those who have looked at the future in terms of solar and renewable resources, including colleagues at Princeton and at the Solar

Energy Research Institute, believe that at some point in the future the cost of solar and renewable to produce hydrogen will be competitive. This clearly must be the goal that we seek.

We lack a strategy in terms of production. Like electricity, as has been mentioned, hydrogen is not naturally occurring and it does require energy to produce. If we use natural gas, it is true today that carbon dioxide is produced in reforming.

The only economic way of producing hydrogen in large quantities from electricity is low-cost hydro, which is not an energy source we have a lot of future capability to develop, or low-cost nuclear, which is not a resource that is being advocated today for production of hydrogen by most people.

The long-term production strategy must lead to solar and renewables. We lack a strategy in terms of the application of hydrogen. Its only fuel use now, as has been mentioned before, is in space. We need to develop the applications that will comment on briefly to allow that market pull to encourage us to produce alternative ways of producing it. And, frankly, we do lack a strategy on dealing with safety issues, and that must also be considered.

On behalf of the NHA, I am not here to advocate a 1970s view of a hydrogen economy, a view that was based upon depletion concerns, depletion of energy resources, a position that was based upon concerns about oil dependency overseas or our dependency upon production overseas. And I am not here to suggest that hydrogen is a panacea today for any energy problems.

But, we are advocates of developing a U.S. hydrogen capability, a U.S. capability, and I think that capability does have to have two prongs. We have to develop the applications, beginning with niche applications. Those applications will pull the market for expanded and new technologies for production.

Aerospace is clearly one of those applications. It can lead to investigation into global hydrogen distribution systems, storage technologies. We are an advocate of NASP funding for continued research in hydrogen fuel use, and we do support Title II of this bill as a result.

Secondly in terms of applications, the niche in ground transportation needs to develop. Out of that will develop considerations of the infrastructure for distribution and handling of hydrogen as a more popularly handled commodity, considerations of storage technologies, the integration of systems for cars and buses in their use of hydrogen and, of course, the general addressing of the problems of popular handling and usage of hydrogen.

The third application is electric generation and storage. There is a lot of work going on in this country and others in fuel cell technologies. Fuel cell technology is the natural link for anybody's view of hydrogen production and use because it is what gets you to electric generation from hydrogen.

Developing the application potentially for solar-produced, for renewably-produced hydrogen to fuel fuel cells and to use that in hydrogen storage as an energy storage and balancing mechanism compatible with the use of renewable resources is the third application I would highlight this morning.

The second prong, I think, of developing our U.S. hydrogen capability is to initiate an expanded hydrogen production R&D effort.

There is no doubt that our priority ought to be focused on renewable hydrogen, but let us not forget that in the near term one can produce hydrogen with conventional steam reforming at some energy loss, and if that hydrogen is used in, for instance, ground transportation, a fuel cell-powered car or bus, there is an energy efficiency and a carbon dioxide benefit that results. It is not overall a penalty for hydrogen. A gasoline-fueled car is far inferior to a hydrogen-fueled fuel cell vehicle.

In the intermediate term, coal clearly will play a role in the production of hydrogen for these applications that will be developing and in the long term again the programs such as at the University of Hawaii, at the Hawaii Natural Energy Institute, will lead to renewable energy-based technologies.

I think there is lots to like in this bill, in S. 639. Section 103 and its focus on a comprehensive five-year plan for hydrogen that is goal-driven and addresses both production and use is good.

Section 105, in its focus on a technology assessment, an inventory, if you will, and an information transfer program for hydrogen and its emphasis on market-driven opportunities and the evaluation of commercial applicability, these words ring well for my industrial members.

Section 106 and its coordination among Federal efforts is a valuable section of the bill.

I would like to comment on section 104, the development of a plan for large-scale demonstrations. I named three technology areas, each of which has some relevance in today's world for demonstration. In ground transportation, in Colorado and California, where environmental problems with air quality are so clear, a plan for eventual demonstration of hydrogen-fueled vehicles would make a lot of sense and one could enumerate opportunities in aerospace and electric generation as well.

Finally, in the bill we applaud the creation of a hydrogen technology advisory board. That is an appropriate body, we feel, and its makeup, as identified in the bill, would be appropriate for such a long-term effort.

Title I is a portion of the bill—and that is what I am addressing this morning—that I think everybody can like. It addresses current environmental concerns, but it does it with a long-term solution. Hydrogen is a long-term solution.

Secondly, it has appropriate roots in markets, in economics, and in practical steps to be taken now. Thirdly, its first steps are quite appropriate for the nature of the problem today—assessment, planning, small-scale demonstration.

Finally, its budget is modest. $3 million, I think, for the first year, obviously not an order of magnitude larger than today's funding. Our global neighbors are spending a lot, lot more.

This bill, I think, does not compete with oil, gas and coal interests because those are the fuels that are going to be used.

On behalf of the Hydrogen Association, I would like to send a clear signal to the Senate. There is market interest in hydrogen technologies. At our meeting earlier this month was announced a hydrogen technology partners venture fund for the development of niche hydrogen technologies. They are funding fuel cell research now and are looking for other venture opportunities.

The market interest is growing. Industry is committed to working with government to bring new technologies to the marketplace in hydrogen production and application, but the development of technologies does require the help of the Federal government.

I would like to thank you for the opportunity to appear here this morning and I would be happy to answer any questions.

[The prepared statement of Mr. Serfass follows:]

TESTIMONY

on

S. 639

"The Hydrogen Research and Development Act"

by

Jeffrey A. Serfass
President
National Hydrogen Association

before the

Subcommittee on Energy Research and Development

Committee on Energy and Natural Resources

United States Senate

March 30, 1990

Testimony on S. 639
"Hydrogen Research and Development Act"
March 30, 1989

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Subcommittee on Energy Research and Development

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Good morning, my name is Jeff Serfass. This morning I am speaking as President of the National Hydrogen Association (NHA). On behalf of the NHA, I would like to thank Chairman Ford, the subcommittee, and subcommittee staff for the opportunity to appear before you today to offer our support for S. 639, "The Hydrogen Research and Development Act." I would like to speak to industry's view of the long term potential of hydrogen as an environmentally superior energy vector and fuel. I would like to go further, though, and address the need for a transition strategy -- one that is realistic, yet promises to be effective -- to proceed step-by-step toward greater hydrogen utilization. In so doing, I am happy to provide some brief oral comments on our interest in S.639, but ask that my entire written testimony be included in the record.

"I would like to . . . address the need for a transition strategy . . . that is realistic, yet promises to be effective -- to proceed step-by-step toward greater hydrogen utilization."

The National Hydrogen Association, formed a year ago, is an organization of members from industry, small business, academia and state and federal entities. The NHA was formed to organize the natural U.S. industrial and research interests in hydrogen, to develop plans for appropriate research and development, and to assess the profit-driven industrial opportunities in hydrogen production and utilization. Attached is a list of our current membership, which is growing, and a Fact Sheet describing our organization in more detail.

"[The NHA's] mission is to foster the development of hydrogen technologies and their utilization in industrial and commercial applications and promote the transition role of hydrogen in the energy field."

Our mission is to foster the development of hydrogen technologies and their utilization in industrial and commercial applications and promote the transition role of hydrogen in the energy field. The National Hydrogen Association:

- promotes the long-term development of hydrogen production and utilization technologies;
- promotes the development and expansion of practical near-term applications for hydrogen;
- recognizes aerospace as one of the very important near-term identifiable applications for hydrogen fuel;
- assists in the transfer of technology, especially from NASA and academia, to the private sector -- and from research to practical application; and
- recognizes the environmental advantages of hydrogen fuel and the need to make it affordable to mass markets in a safe and efficient manner.

"We would like to see a recommendation from your subcommittee that this bill move forward. . ."

These items are recognized by industry as important to developing the potential of hydrogen. These items are key components of S. 639. Therefore, we would like to see a recommendation from your subcommittee that this bill move forward to mark-up.

The Forever Fuel

Hydrogen, today, is produced from natural gas and as a chemical by-product for use in the merchant market, large industrial processes, and transportation. As used in most current markets, hydrogen is

"As used in most current markets, hydrogen is viewed as a chemical, but in transportation it is viewed as a fuel."

viewed as a chemical, but in transportation it is viewed as a fuel. Companies have been delivering hydrogen gas to the merchant market for over 50 years and in liquid form for over 20 years. The merchant market includes hydrogenated fats and oils for use in food, electronics manufacturing, and many other common industrial processes. A large amount of hydrogen is used as a chemical feedstock in petroleum refining, ammonia and fertilizer production, and is usually produced on-site. For transportation, the United States market has been limited to space vehicles -- for now.

"The application of hydrogen can certainly be expanded and industry would like to see that happen."

"Senator Wirth may remember the demonstration of the hydrogen-powered Mercedes on Capitol Hill by Daimler-Benz of West Germany."

The application of hydrogen can certainly be expanded and industry would like to see that happen. For example, space travel does not have to be the only hydrogen fuel consumer. Last September, Senator Wirth may remember the demonstration of the hydrogen-powered Mercedes on Capitol Hill by Daimler-Benz of West Germany. Also, in the Senator's state of Colorado, Hydrogen Consultants, Inc., is working on hydrogen demonstration projects. Two of these are relevant to Title I of this Bill:

- A hydrogen-powered coal mining vehicle which emits no toxic fumes and burns with less oxygen, on display in Minnesota's Twin Cities Research Center; and
- A light pick-up truck which is owned and demonstrated by Riverside, California's division of the American Lung Association.

"Hydrogen-powered coal mining vehicles could be used in coal mines in Kentucky and West Virginia."

Hydrogen-powered coal mining vehicles could be used in coal mines in Kentucky and West Virginia. For those mine sites with power generating stations, the hydrogen for the vehicles could be produced at the site; or hydrogen could be piped from hydrogen production plants like the one in Ashtabula, Ohio -- Senator Metzenbaum's state. Los Alamos National Laboratory is helping to evaluate fuel cell cars and buses -- an environmentally superior alternative to gasoline engines -- one that utilizes hydrogen.

"Los Alamos National Laboratory is helping to evaluate fuel cell cars and buses -- an environmentally superior alternative to gasoline engines . . ."

Though there are small demonstration projects in the United States and around the world, hydrogen fuel is not limited to current technology like the internal combustion engine. Research is currently being done in the U.S., Canada, West Germany and Japan to integrate fuel cells into hybrid vehicles to give them greater range and less recharge time. For all fuel cells, the fuel of choice is hydrogen. The development of this propulsion system is at such a stage that we may see demonstration vehicles on the road within five years.

From an environmental point of view, hydrogen contains **no carbon, no nitrogen and no sulfur**. It is a pure element, and we have a virtually inexhaustible supply. Consequently, it has virtually no emissions adding to Global Warming and acid rain, two topics of Congressional concern. Its primary emission is water vapor. The problem is that it must be produced using another energy resource -- natural gas today, but solar energy tomorrow:

"Its primary emission is water vapor."

- Cars utilizing an alkaline fuel cell, fueled by hydrogen conveniently stored in any one of several forms, are significantly better than gasoline engines, in terms of carbon dioxide and all other emissions of concern, even if the hydrogen is produced from conventional steam reforming of methane initially.
- Later, the hydrogen may be produced from coal, with the benefit of transferring automobile pollution entirely away from the local regions most acutely effected.
- Eventually, the hydrogen will be produced from one or more solar energy technologies.

Environment vs. Market

The environmental advantages of hydrogen are unparalleled, but that alone will not drive the market today. Industry must look at hydrogen from a different perspective -- the economic market.

The economic market for hydrogen fuel is practically non-existent, the largest consumer being space launch systems as mentioned earlier. Realistically, hydrogen pumps at gas stations are many years away, requiring successful development efforts in hybrid vehicles. The long-term environmental advantage is realized only with hydrogen produced by renewable energy.

Competitive economics require that we reach our long-term objectives through prudent steps aimed at identifying, developing and

> ***"Competitive economics require that we reach our long-term objectives through prudent steps aimed at identifying, developing and expanding near-term business opportunities."***

expanding near-term business opportunities. Long-range, high-speed air travel is one of these potential market niches. Though the budget funding for the National Aero-Space Plane (NASP) has yet to be determined, hydrogen fuel is an integral part of that program. Because of the high-speed, air-breathing engine design of the NASP, hydrogen is the only fuel for this valuable aircraft.

"Because it is in our nature to go faster, not slower, the high-speed engines of the NASP will be scaled to other planes, thus opening a new market for hydrogen . . ."

The fuel research associated with NASP is critical to assessing the viability of hydrogen for other transportation markets. Because it is in our nature to go faster, not slower, the high-speed engines of the NASP will be scaled to other planes, opening a new market for hydrogen and the beginning of an infrastructure for this fuel. Thus, Title II is an important section of this bill for industry and we urge the subcommittees to support the NASP program as the lead R&D program for hydrogen as an aerospace fuel.

In addition to the benefits in Title II, enactment of Title I would allow significant hydrogen production research which might lead to breakthroughs in the reduction of the cost of hydrogen through:

- more efficient electrolyzers for production from electric energy; and
- solar and other renewable-energy produced hydrogen.

"President Bush's proposed amendments to the Clean Air Act, and related initiatives in Los Angeles, Denver, Phoenix, and other areas, to develop alternative fuel transportation, scarcely recognize the long-term potential for hydrogen and related technologies."

This would allow serious consideration of hydrogen as a ground-based transportation fuel. President Bush's proposed amendments to the Clean Air Act, and related initiatives in Los Angeles, Denver, Phoenix, and other areas, to develop alternative fuel transportation, scarcely recognize the long-term potential for hydrogen and related technologies.

Title I would also encourage the development of electric generation technologies, including fuel cells. Fuel cells, which require hydrogen and oxygen in air to produce electricity (and water vapor and some heat), are the obvious link between hydrogen fuel and electric power generation. The environmental advantages of this technology beat all existing and planned air quality standards for emissions by a factor of 10 or more.

Enactment of Title I would broaden hydrogen research to areas of other end-use applications, materials and storage technologies. And, part of broadening the focus of hydrogen research includes technology transfer, an important element in developing new markets; an important step addressed in S. 639.

Facing the Facts

Senator Ford, it is clear that hydrogen research and development is not currently at the top of the list of our nation's priorities. This is true even though renewable energy technologies, which include hydrogen produced from solar energy, have less impact on the environment than any fuel currently in use. However, even the environment seems to fall behind the issues of deficit reduction, the war on drugs, and education on President Bush's domestic priority list. Because we are able to face the fact that the development of hydrogen fuel is not high on the current political agenda, we are supportive of the modest appropriation amounts in S. 639. We feel they are realistic

"...West Germany and Japan, are spending $50 million and $20 million per year on hydrogen research, respectively."

amounts given current budgetary constraints and their impact is lessened because they are spread over five years.

The appropriation of adequate funds is always the issue that is the most difficult to address. Our foreign neighbors, specifically West Germany and Japan, are spending $50 million and $20 million per year on hydrogen research, respectively. According to the budget in this bill, we do not approach those kinds of numbers until the 5th year.

This bill has been before your subcommittee for a number of years now. During those years, while the bill was unable to move from the subcommittee, foreign countries, more than just Japan and West Germany, have been spending, and there seems to be no reduction in sight.

Wouldn't you like to hear testimony for a change that stated we are ahead of other countries in a particular scientific technology? We cannot suggest to you that if S. 639 is enacted that that will happen, but let's take one step at a time. Without the funding; without an integrated program that has clearly defined research objectives; without a program that includes nearer-term research to arouse the commercialization instincts of private industry; without a framework for technology transfer to the private sector; without all of these factors addressed somehow, we cannot stay competitive.

. . there is market interest in hydrogen technologies, and industry is committed to working with the government to bring them to the marketplace."

On behalf of the members of the NHA, let me send a clear message to Congress: there is market interest in hydrogen technologies, and industry is committed to working with the government to bring them to the marketplace. But, development of these technologies does need the help of the Federal Government.

Thank you for your patience and attention. I will be happy to answer any questions or to supply additional information for the record.

National Hydrogen Association

FACT SHEET

Background

Hydrogen, the world's most abundant and basic chemical element, was popularly considered in the 1970s as the environmentally superior fuel and feedstock of the future -- the energy carrier for the time when existing carbon-based fuels would be depleted. This picture of the '70s, in which fossil fuel supplies would soon be dwindling, is not the picture we see today. And yet, growing concern over regional and global environmental problems encourage a revised assessment of the future role of hydrogen.

Hydrogen is used widely in industry today, and yet, the important commercial role of hydrogen as a commodity is not often recognized. Its use in metallurgy, cosmetics, food processing, and semiconductor materials is relatively unknown outside of these industries. Its role in chemical processing, refining and fertilizer production is critical. Hydrogen is the fuel for fuel cells for electric generation, and is a potential medium for energy storage, with off-peak electrolytic hydrogen production and on-peak electric generation.

The first hydrogen economy, once envisioned for the future, already exists in space. Hydrogen is used for propulsion, electric generation, water production and other on-board spacecraft functions. The opportunities for transfer of hydrogen space technologies to terrestrial applications, through combined industry, government and research efforts, are large.

Today, hydrogen can play a role as a transition fuel and feedstock for extending the useful life of coal, natural gas and petroleum resources. Coal, gasified to produce hydrogen, becomes more useable and environmentally acceptable at the point of use. Oil and gas supplies can be extended with hydrogen-enhanced products and processing. Steam reforming will continue to be the most economical transition process for producing this hydrogen, with some increase in the use of electrolysis. Beyond this transition, hydrogen produced from, solar photovoltaic technologies may be the ultimate, abundant, renewable-based energy form.

National Hydrogen Association Forms

The National Hydrogen Association was born out of a Hydrogen Workshop, on November 16 and 17, 1988, held at the Electric Power Research Institute in Palo Alto, California:

> *Whereas, a group of organizations and individuals have met on 16 and 17 November 1988 to discuss the research and commercial opportunities and solutions to future global habitability and energy/materials resource use.*
>
> *Whereas, a model of hydrogen industry, university and government cooperation (Hydrogen Industry Council in Canada) has been presented and shown to be effective.*

Whereas, other nations are pressing ahead to develop new commercial opportunities for using hydrogen as a fuel and feedstock.

Whereas, there is no single significant champion or advocate for the hydrogen-related industry in the United States.

Whereas, hydrogen represents future opportunities for electrical power, fuel, chemical, and aerospace industry sectors.

NOW, THEREFORE, BE IT RESOLVED THAT:

1. *We initiate the formation of an ad hoc Hydrogen Industry Task Force made up of industry members with support and consultation from university and government members.*
2. *The Task Force will be responsible for developing a position paper, marketing approach, and business plan to form a ...*

National Hydrogen Association

Mission:** **To foster the development of hydrogen technologies and their utilization in industrial and commercial applications and promote the transition role of hydrogen in the energy field.

The National Hydrogen Association was formed by a group of ten industry, university/research and small business members on February 28, 1989 and incorporated on March 22, 1989 in Washington, D.C.

Objectives

The initial objectives of the NHA, in addition to developing a broad base of industry, academic and government support, are to:

1. Assist in **information transfer** among research, industrial and government programs.
2. Provide a **national focal point** for hydrogen interest that can assist state and federal government organizations and private industry in developing hydrogen initiatives in emerging technologies.
3. Develop public and government **education programs** that provide information on the long term potential for hydrogen as an energy carrier and for hydrogen technologies.
4. Develop approaches to specific **consortium-based projects** that can serve as innovative models for production, storage and utilization of hydrogen.

Technological Areas of Interest

- Aerospace and aircraft propulsion
- Aerospace technologies for electric generation and other applications
- Biomass gasification
- Electric generation and storage
- Electrolysis
- Fuel cells--acid, oxide, carbonate and polymer
- Hydride storage
- Numerous industrial processes that use hydrogen
- Production, storage and transport of liquified hydrogen
- Production of hydrogen from coal and other hydrocarbon feedstock
- Purification and separation of hydrogen
- Photovoltaic production of hydrogen
- Transportation

Program Elements

The following is a list of some of the program elements that the NHA Board of Directors and members will be considering at its early meetings:

- Develop and regularly update an **information resources** on hydrogen production, utilization and **storage**.

- Conduct an **assessment of emerging hydrogen technologies** to focus industry, research and NHA efforts, and update it regularly.

- Conduct an **annual technical meeting**, and publish periodic **hydrogen news and an NHA newsletter** for information transfer among members.

- Develop **communication with national organizations of other countries** to promote cooperative efforts and information transfer.

- Provide an industrial, academic and government **focal point for NASA, DOE, DOD and the Solar Energy Research Institute** to obtain technical and research input.

- Conduct a **government affairs** program that provides useful hydrogen information to federal and state organizations considering environmental, transportation and other topical initiatives.

- Conduct a **public education** program to provide useful information on the long- term opportunities for hydrogen technologies, safety awareness, and hydrogen as an energy carrier.

- Conduct a **research review** program that seeks new ideas for hydrogen production, storage and utilization.

- Conduct a **project screening** program that seeks promising joint risk-shared projects among private industry, research and government organizations.

Membership

Founding membership is open to all large and small industrial organizations with an interest in hydrogen production, storage or utilization, and university and other research organizations. Membership entitles your organization to elect representatives from your class to the Board of Directors. Early Industry Founding Members will be entitled to a seat on the Board. All Founding Members will be invited to participate in all Board, membership and committee meetings throughout 1990 to assure a voice in important technical, program and organizational activities during formation.

1989 Membership Fees are as follows:

Industry Founding Member	$6,000
University/Research Founding Member	$1,100
Small Business Founding Member	$1,100

In addition, for government organizations interested in receiving NHA information and the opportunity to attend member meetings, but unable to join a private industry/university organization, a Subscriber category is offered with the following fee:

Subscriber	$1,000

In Conclusion ...

Hydrogen is an abundant element capable of becoming the major cornerstone of energy systems in the next century. Members of the National Hydrogen Association will be seeking short-term results from information transfer activities and identification of research and business opportunities, while keeping an eye on the long-term direction of energy and environmental technology issues and the opportunities they present.

900327

National Hydrogen Association

MEMBERS - March 26, 1990

Industry:

Airco Industrial Gases
Air Products & Chemicals
Allied-Signal Aerospace Company
Liquid Air
Union Carbide Industrial Gases/Linde Division

University/Research:

Center for Electrochemical Systems & H_2
Research/Texas A&M
Clean Energy Research Institute/University of Miami
Hawaii Natural Energy Institute/University of Hawaii
Institute of Gas Technology

Small Business:

Cryogenics Industries
Energy Research Corporation
Hydrogen Economy Corporation
Orbital Technologies Corporation
Sunox General Hydrogen Company

Subscriber:

Baltimore Gas & Electric
Kinetics Technology International
McDonnell Douglas Space Systems Company
NASA
Northern States Power Company
Public Service Electric & Gas
San Antonio Air Logistics Center

Senator **Ford**. Thank you very much.

Doctor, do you want to proceed, and then I will have a question or two for each of you.

STATEMENT OF DR. PATRICK K. TAKAHASHI, DIRECTOR, HAWAII NATURAL ENERGY INSTITUTE, UNIVERSITY OF HAWAII

Dr. **Takahashi**. Thank you, Senator Ford, Mr. Chairman, honorable staff.

Senator **Ford**. Honorable staff?

Dr. **Takahashi**. It is nice to be back.

Senator **Ford**. Like one of the former members of this Committee said, when you refer to staff reminds him of his favorite verse in the Old Testament: Moses leaned on his staff and died. [Laughter.]

Dr. **Takahashi**. I am sure you are joking, Senator.

This statement was jointly prepared by the Directors of the research institutes of the universities that were previously mentioned from Florida and Texas. I would like to recognize the fact that they helped me write it and to have the entire statement for the record.

Senator **Ford**. It will be included in the record.

Dr. **Takahashi**. Good. If I could just summarize and maybe slightly personalize my statement, I would appreciate it.

It was just about a decade ago, I believe, that I helped this very Subcommittee and Senator Matsunaga draft the original hydrogen bill, which has withstood the test of time, you might say, because it looks fairly familiar from the first draft. It is still a good bill, and I think things have changed to the point where the possible passage looks a lot more encouraging today.

I might add as a kind of historian for this subject and research director a number of things that have happened since this decade ago introduction. That is that about six years ago the Department of Energy asked my institute and the Florida Solar Energy Center to work with the Solar Energy Research Institute to come up with a technology status assessment of what has to be done, what are the research priorities that can bring us into a more meaningful renewable hydrogen program in the future.

We did produce this report. The SERI published it. And since then there has been a series of research programs, all of which have been peer-reviewed. Just to give you an idea of the kinds of work we are doing at the University of Hawaii, as one of the four centers assigned this task, one project has to do with converting sunlight to hydrogen, using water as a feedstock, by producing new kinds of materials for electro-chemical production of this fuel.

Second, we have a group looking at genetic engineering techniques to see if photo-biological concepts can eventually in the long term reduce the cost of hydrogen production.

We have a third project that is almost mystifying because in the past when you converted biomass to hydrogen you had the problem of taking the water out before you gasified it. It turns out that if you do it under certain conditions of temperature and pressure you want the water in there, so we deal with wet biomass, where the water itself becomes a feedstock because of the dissociation conditions at the temperature, so we produce more hydrogen with wet biomass and we see an interesting long-term cost savings on this.

The fourth and final project that we have—and again all of these are peer-reviewed by the Department of Energy system—has to do with, you might say, designer materials to store hydrogen. We have designed some complex molecules where if you have given temperature and flow rate and pressure conditions we can design the molecule to produce the exact storage conditions you want—something that was not available even two years ago.

So there are various breakthroughs that I think are in the offing. We have not quite attained them yet, but this just represents one of the kinds of programs going on around the nation that we think will support the kinds of focus that both Mr. Davis and Mr. Reck promoted on what should be happening with the research program of this nature.

Let me close by saying that Senator Matsunaga is the chief sponsor of this bill and I was with him when the seabed mining bill passed this Committee. It was authorized by this Committee after ten years of work in the Senate. And after I left the Senate a few years ago I noticed that Senator Matsunaga's Peace Academy bill finally passed, after 20 years of work by the Senator.

In this particular case, hydrogen is a very important subject for him. I think, as the witnesses have shown, it indicates that this is a visionary bill that has impressive long-term potential for the nation, and I would like to urge this Committee to pass favorably the bill itself. We are strongly supportive.

In final conclusion, let me state that Hawaii is hosting the next biannual World Hydrogen Energy Conference in July of this year. We have 50 countries being represented, maybe 500 scientists. We would like to urge you, Senator Ford, and members of this Committee and your staff to attend. I have a brochure here in front of me that I will pass on to Dr. Cooper. We would like someone here to even make a statement at the conference, perhaps, summarizing the legislation that is occurring in Congress.

So, with that, I thank you for having me here.

[The prepared statement of Dr. Takahashi follows:]

TESTIMONY ON
THE HYDROGEN FROM RENEWABLE ENERGIES PROGRAM

by

Patrick K. Takahashi
Director
Hawaii Natural Energy Institute
University of Hawaii at Manoa

David L. Block
Director
Florida Solar Energy Center
University of Central Florida

John Appleby
Professor and Director
Center for Electrochemical Systems and Hydrogen Research
Texas A&M University System

T. Nejat Veziroglu
Professor and Director
Clean Energy Research Institute
University of Miami

Given before

U.S. Senate
Committee on Energy and Natural Resources
Subcommittee on Energy Research and Development

March 30, 1990

We want to thank the subcommittee for this opportunity to speak today on the subject of the hydrogen from renewable energies program. With Congressional support, the Florida Solar Energy Center, the Hawaii Natural Energy Institute, the University of Miami's Clean Energy Research Institute and Texas A&M Center for Electrochemical Systems and Hydrogen Research have been working closely with the Solar Energy Research Institute and U.S. Department of Energy headquarters in advancing research on hydrogen production, storage and use. Over the last four years, this national R&D program has been quite productive. We have identified the research issues that need to be resolved for a national transition to hydrogen energy production from renewable resources, and we have begun research and analyses to resolve those issues.

Before we present details with respect to the act, we want to state that this legislation is critically needed, and we highly support it. One of the most vital aspects of the act is recognition that energy research must integrate renewable energy fuel production with technologies for its use. We believe this act is supported by several energy-related facts now dawning on the Nation's consciousness, facts that will significantly affect national growth and security during the next 10 years. These facts are:

- The nation's economy is inextricably tied to energy costs and availability.
- Demand for electricity is rapidly expanding, and generating shortfalls exist or are imminent in all regions of the country.
- Attempts to encourage transportation fuels other than oil have been unsuccessful, weak, often misdirected, and too variable to lead to any long-term solutions.
- Foreign control of oil resources threatens not only the national economy but also the national security.
- Environmental risks posed by fossil energy consumption and nuclear power production threaten both national and global welfare.

These facts combine to form a set of economic and environmental problems that is most difficult and complicated. The ultimate solution will involve an eventual shift to the use of renewable energy resources with a strong emphasis on developing electrical and transportation alternatives. The Hydrogen from Renewable Energy Program provides an excellent and much needed first step in this process and establishes the required Congressional leadership.

In the final analysis, only hydrogen produced from renewable resources can meet our long-term power and environmental concerns. By producing the hydrogen fuel of the future from renewable resources, we can ensure that its production does not create as many problems as it solves. Enhanced R&D for hydrogen from renewables is an absolute must, if we are to make the transition from globally polluting to benign power sources.

We have previously testified on the importance of development of hydrogen fuels from renewable energy resources. Your Committee and the Congress have consistently supported our work and our program on hydrogen from renewable energy resources, which is conducted by our consortium of four university institutes. To date, the consortium has conducted detailed studies on all aspects of hydrogen production, storage and utilization. Experiments have begun on hydrogen production using advanced photoprocesses and photobiological methods. In the storage area, research has focused on enhanced metal hydrides, novel new compounds, chemical carriers and mixed gases. Safety issues are being addressed, as is hydrogen fuel utilization in vehicles. The consortium has also conducted analyses of various scenarios for transition to the hydrogen economy, and has evaluated fuel cell technology research and utilization. The work conducted by the consortium is critical in that it lays the groundwork for future hydrogen R&D and for the renewable energy act being addressed here today.

While the U.S. hydrogen program has made strides during its four years of existence, other nations, particularly Japan and West Germany, are fast out-pacing U.S. research on and development of hydrogen energy alternatives. Last year, Japan committed to hydrogen R&D more than 10 times the funding of the United States. West Germany spent $50 million for hydrogen research in 1988-89. West German companies, such as Daimler-Benz and BMW, are already producing hydrogen-powered cars and the West German government is now supporting the world's largest renewable hydrogen project. This project proposes to produce hydrogen by photovoltaic electrolysis in North Africa and ship the hydrogen fuel so produced to Germany.

Foreign competition also comes from unexpected quarters. Last fall, at the 7th World Hydrogen Energy Congress in Moscow, those in attendance witnessed two surprises. The first occurred when the USSR keynote speaker addressed the greenhouse effect and the huge potential of hydrogen to ameliorate its damage to our world. In fact, the hydrogen solution to global warming was the chief subject of discussion among the more than 700 scientists in attendance from all over the world. The second surprise was the presentation of a film showing Aleksei A. Tupolev's historic first flight of a modified Soviet TU-155 commercial jet, powered only by liquid hydrogen during its 21-minute flight. America's proposed National Aerospace Plane will have to gain significant ground to catch up with the Soviets. If technological competition in hydrogen research and development can come from the Soviet Union, given their current economic turndown, it can come from nearly anywhere.

The Nation and the Department of Energy is poised on the brink of significant advances in hydrogen R&D. A National plan for hydrogen is being prepared. This act would make expansion of hydrogen research and development efforts a logical extension of the interest now being expressed within the Department of Energy. We would hope that both efforts within Congress and the Department of Energy will be viewed as mutually reinforcing. We also wish to send a clear message that we, as representatives of the academic community, support the Committee's leadership efforts toward the passage of this far-reaching and much needed act, and will continue to complement the national program.

Senator **Ford**. Was that the OTEC project you talked about, the seabed mining? Did not Sparky—excuse me, Senator Matsunaga—have the OTEC project? Was that one of his?

Dr. **Takahashi**. Yes. Senator Ford, Senator Matsunaga had two ocean-related bills. One had to do with seabed mining of strategic metals. The second had to do with OTEC, which is not the purpose of this particular hearing, but that also has come very far and we see good things happening.

Senator **Ford**. Well, I have a flashlight in my office that I was just telling the good Doctor I have. I have had it better than a dozen years now, I think, and the other day I was showing it to some students and it still lights.

Dr. **Takahashi**. That shows how great OTEC can be.

Senator **Ford**. I just want to tell you if it works that well for everything else, we ought to just shelve everything else and go for that, because my flashlight still works.

That is another indication of being farsighted, even though it is a tough row to hoe and hard to get people to follow along. It was like when I was young and energetic I was after synthetic fuels and so forth from coal.

Let me ask both of you, and particularly you, Mr. Serfass, I gather that the critical issue in hydrogen research is developing a way to produce hydrogen from water at low enough cost. Would that be a generally good statement?

Mr. **Serfass**. Yes, I think so. I think we certainly recognize that if we can produce hydrogen at low enough cost, with the proper environmentally-acceptable technologies, that we have pretty well created the fuel that, at point of use, is nearly the perfect fuel.

Senator **Ford**. Are, then, we talking about a very, very low-cost source of electricity?

Mr. **Serfass**. Yes. But there are other technologies that really are being developed under Department of Energy sponsorship now at a relatively low level but nevertheless under way at the Solar Energy Research Institute to develop direct solar energy conversion technologies that do not necessarily involve the intermediate step of producing electric energy.

So all of the options, both low-cost electric energy generation and other renewable technologies, ought to be explored at this time. I do not think we know yet what the right solutions will be.

Senator **Ford**. Doctor, you indicated that you were using solar energy. Does widespread use of hydrogen have to wait on solar photovoltaic or nuclear energy or fusion to become very, very inexpensive—I started to say cheap—and how long do you think we will have to wait?

Dr. **Takahashi**. Let me answer that in two parts, Senator Ford. First, I think the photovoltaics, nuclear power, or some of those alternatives, have to be developed, and it is possible that it can become cost-effective means for hydrogen production. It is possible.

But in all of those instances you pretty much will have to produce electricity first for electrolysis of water, and therefore you are faced with this double process of producing hydrogen.

What some of us are doing—and especially at SERI and the University of Hawaii—we are looking at eliminating the electricity step, as I said, genetically engineering, say, a bacterium that can, using sunlight as its energy source, break down water and produce the hydrogen directly. This way we eliminate the extra cost of the hardware that would be necessary under these options that you mentioned.

So both I think have potential—the photovoltaics, the nuclear, over the next 10 or 20 years, and some of the more esoteric—photobiological and photoelectric chemical concepts—over the next 20 to 50 years.

Senator FORD. You have been around this institution for a while and understand its inner workings. This bill calls for $155 million over the next five years. Each section is graduated in $3 million and so forth for part 1, and then $10 million increments over a five-year period.

Do you think that is a sufficient budgetary request in order to keep us on the right track and moving with some sense of urgency?

Dr. TAKAHASHI. Again I can answer this in two parts, Senator Ford.

Senator FORD. You are kind of a two-part fellow, are you not?

Dr. TAKAHASHI. The bill itself and much of the budgetary details with a period of time, you might say, before Gramm-Rudman, before our huge budget deficits, and in those days we felt that that kind of program would have been ideal under the conditions.

Today, of course, given these budgetary support figures, over time we can be the world leader. Considering, though, the fact that we do have a budget crisis, we do have deficits, a sum as a percent of what you see there would be better than nothing at all. Right now the support can be enhanced. I think an enhancement is all we are asking for to lead us into the future on a more solid foundation.

So yes and no.

Senator FORD. You gave the right answer—yes and no.

Do you have any further comment you would like to make? Otherwise, I have no further questions of either of you gentlemen.

Mr. SERFASS. Senator, if I can just comment on the last question, I think over several recent years the proposed funding for Title I has been decreased. It was also, I believe, $100 million or so recommendation. It is a $55 million recommendation, and that certainly does reflect to some extent the changing budgeting situation.

It is a relatively low budget for something that for the U.S. has quite a high payoff, and it is also relatively low compared to Germany, Japan, Canada, and other countries. Most people believe that there is a whole array of technologies that for the countries that begin and stay on the leading edge are going to have a significant impact sometime, possibly after the turn of the century.

Dr. TAKAHASHI. I would finally add that the four universities are working very closely with SERI and the Department of Energy, and we have a good working relationship. We hope that you can work out some compromise with the Department to come up with a bill.

Senator FORD. Fine. Thank you both very, very much. I appreciate your coming today. If you have any additional comments after you get away and begin to think about it, the Committee would welcome those statements and would love to have them. You might do it in a timely manner so we can get to a markup on this bill.

The next two witnesses and the final panel today is Robert B. Moore, Technical Manager, Process Systems Group, Air Products and Chemicals, and Willis Hawkins, Senior Advisor on Technology Development from Lockheed. If you two gentlemen will come forward, we look forward to your testimony.

Mr. Moore, you may start with your statement. As with the other witnesses, your statement will be included in the record in full. If you would like to highlight it, why we would entertain that also.

STATEMENT OF ROBERT B. MOORE, AIR PRODUCTS AND CHEMICALS, INC.

Mr. MOORE. I would like to thank you, Chairman Ford, and your staff for allowing me to testify before you today.

My name is Bob Moore. I have been employed by Air Products and Chemicals for about 30 years now. My initial assignments were in the manufacturing of liquid hydrogen in the West Palm Beach facilities. This plant was built with Air Force funds in the late 1950s for developing high altitude bomber engines. It was later converted into the space program for the upper stages of the various space vehicles.

I felt I was fortunate because this was the first commercial demonstration of liquid hydrogen. I have had a chance to see hydrogen develop from that into what is now a commercial market.

We did a number of things at the plant which were first of a kind—the first large-scale. We did ship liquid hydrogen through pipelines for several miles, which had never been done before. We were the first people that had to figure out how to ship liquid hydrogen in a trailer throughout the United States because that was the only source at that time.

We used three different technologies there. Part of my reason is we keep talking different technologies for making hydrogen this morning. The first plant started with reforming of propane to make hydrogen. The second facility was based upon crude oil, partial oxidation to make hydrogen. It was later converted to partial oxidation of natural gas. So at that facility I saw three different feedstocks being used to make liquid hydrogen.

After that experience, I had an opportunity to spend another four years of my career in the design, construction and the early training of operators for the startup and early operations of the Air Products-owned and operated facility in New Orleans. Here we made liquid hydrogen using a different technology, starting with natural gas reforming. That is perhaps the most economical technology that is available in today's society.

We added one new thing there which I kind of liked, which was the shipping of liquid hydrogen by barge. It went up to what is now the Stennis space facility. The reason I kind of liked that was I was looking at some pictures today of that, and the size of the pipelines and just the general handling of that is very similar to what will be needed for a space aircraft.

I would like to briefly give the background of Air Products, in that we have been in the hydrogen or liquid hydrogen business for well over 30 years now. We are a major merchant producer and supplier of liquid hydrogen virtually throughout the world. We operate two plants in New Orleans, Louisiana. One is for the space program and the other is for commercial marketing.

We have a third plant in Sacramento, California, which we use primarily for commercial markets. We also operate a facility in Canada and another one was just recently built in The Netherlands, which is now supplying liquid hydrogen to Europe.

The company is a fairly large company in that it has about $2.6 billion a year sales. We are in the chemicals business as well as the gases business. The primary business is gases.

I would like to say that as far as the hydrogen program, we were involved first in the 1950s with the pioneering effort to develop these plants that were installed at West Palm Beach. In the 1960s, we helped with some of the research on the aerospace plane that the Air Force was developing for the future. In the 1970s we were involved in some of the studies which were done for commercial aviation, supplying liquid hydrogen at various airports throughout the United States, and actually through the world, studying what would be the source of hydrogen, how it would be distributed and how it would be used. So we are familiar with that.

We are currently involved with some research for slush hydrogen for the NASP aerospace plane. We have another smaller study which is in the conversion of ortho to parahydrogen. Hydrogen exists in two different molecular forms, and as you go from one to the other you can—well, as you cool it down you want to convert it to prevent the heat release, and as you vaporize it you want to convert it back, as it can provide refrigeration which can be used aboard a spacecraft, and it also increases the fuel value of that hydrogen somewhat.

So we are involved in those programs. We think that this bill supplements all of the activities which we have had to date, so we are strongly in favor of it.

We have many reasons to look forward to an airplane fueled with liquid hydrogen. As stated previously, it is clean-burning and is probably the most environmentally-benign one that we can come up with.

When produced from fossil fuel, there are some advantages in that you have a concentrated source of all the pollutants, such as carbon dioxide, carbon monoxide, sulfur compounds, NOX. Those can all be readily handled at a plant. They are expensive, but they can be done there. When you compare that with the pollutants from the exhaust of jet fuel, those are up in the atmosphere and I have trouble imagining how we can treat those at all.

In the future, the solar-photovoltaic production of hydrogen providing the electricity to liquefy it, that is all totally benign to the environment, so if the economics can be made to happen it certainly is a long step forward.

I would like to say that our feeling is that the technology already exists to make an aircraft, subsonic or supersonic, happen today. I think I heard testimony that they have done it with one engine already. We feel the major challenge is economics. And these economics spread over the entire field, from production, which is a major cost, storage is a cost, transportation is a cost, and then fueling the vehicle is a major cost.

So research efforts could be very worthwhile used in any of these fields, even on down to improving the efficiency of the final consuming engine.

I have with me a tape which Air Products made up. It takes about 12 minutes. I would like to offer it to you. It is primarily a safety film, but as I was watching it the other night it does show the liquid hydrogen facility that we have at New Orleans. It shows loading of trailers and it shows loading of liquid hydrogen barges. So as far as an ability to have a visual concept of liquid hydrogen I think it might be worth the 12 minutes that it would take to watch that.

Senator FORD. We will be glad to accept the film, Mr. Moore.

Mr. MOORE. All right. I would like to kind of conclude that we see a lot of things happening, particularly in the NASP. We think that any activities on this bill should be coordinated with that because what is learned on NASP will certainly be applied to here, and further anything that is learned from this bill would certainly be applicable to NASP. So we think the two ought to keep close contact with each other.

I would like to thank you for the opportunity to testify today, and would be most willing to answer any questions you might have.

[The prepared statement of Mr. Moore follows:]

TESTIMONY

on

S. 639

"The Hydrogen Research and Development Act"

by

Robert B. Moore
Air Products and Chemicals, Inc.
7201 Hamilton Boulevard
Allentown, PA 18195

before the

Subcommittee on Energy Research and Development

Committee on Energy and Natural Resources

United States Senate

March 30, 1990

ABSTRACT OF TESTIMONY

Liquid hydrogen has a long and successful record as the fuel of choice for space vehicles. As a spin-off of the space program, a large commercial market for liquid hydrogen has developed. The safety of loading and shipping liquid hydrogen has been proven over a period of more than thirty years. When there is a need for liquid hydrogen to fuel aircraft, industry will be ready to supply it. Hydrogen-fueled aircraft will use hydrogen in its liquid form to minimize the weight and volume of the storage system. Most of the technology is already available to develop the necessary hydrogen-fuel infrastructure. The real challenge is to improve the economics of the production, handling, and use of liquid hydrogen. Further research and development could help to reduce the economics of the supply and minimize the environmental impact of hydrogen production.

Testimony on S. 639
"The Hydrogen Research and Development Act"
March 30, 1990
before the
Subcommittee on Energy Research and Development
Committee on Energy and Natural Resources
United States Senate

Good morning, my name is Bob Moore. I am a Chemical Engineer and have been employed by Air Products and Chemicals, Inc. for over 30 years. During this time I spent four years in the operations of the world's first large scale liquid hydrogen plants. These plants were constructed for the U.S. Air Force in response to the needs of the infant U.S. space program in the 1950s. An additional three years were spent at the company's New Orleans facility during design, construction, operator training and initial commercial operations of the 32 tons per day liquid hydrogen plant. In these responsibilities I have had considerable hands-on experience in the production of liquefied hydrogen from reformed natural gas and propane and from the partial oxidation of crude oil and natural gas. This experience has included storage and shipping of liquid hydrogen and other cryogenic products by truck, barge, and rail.

I would like to thank Chairman Ford and members of the subcommittee for the opportunity to offer Air Products and Chemicals Inc.'s views on S. 639, "The Hydrogen Research and Development Act."

COMPANY EXPERIENCE WITH HYDROGEN

Air Products and Chemicals Inc. has revenues of approximately 2.6 billion dollars/year. A founding member of the National Hydrogen Association, Air Products is a major commercial gaseous and liquid hydrogen producer and supplier. Air Products operates three liquid hydrogen plants within the United States, one in Canada, and another in The Netherlands. The company is currently involved in the National Aerospace Plane (NASP) program with the production of slush hydrogen and development of para-ortho catalyst. We have supplied liquid hydrogen to the Space Shuttle, Apollo and other government programs. In the late 1950s we pioneered in the development of large-scale liquid hydrogen facilities. In the 1960s we contributed to the Air Force's early aerospace plane R & D. In the 1970s the company studied the feasibility of large-scale use of liquid hydrogen for commercial aircraft.

INTRODUCTION

Hydrogen-fueled aircraft would use hydrogen in its liquid form to minimize the weight and volume of the storage system. Most of the ground-based technology needed to support a future hydrogen-fueled aircraft system already exists. The real challenge is to improve the economics of the production, handling, and use of liquid hydrogen. The current cost of liquid hydrogen, including storage, shipping, and loading losses, is many times more expensive than jet fuel. This high cost can hinder in liquid hydrogen's application as a commercial aircraft fuel. Many steps in the production and utilization of liquid hydrogen contribute to its total cost. These include the production of gaseous hydrogen, purification, ortho-para catalyst conversion, liquefaction, storage, shipping, loading losses, and efficiency of utilization.

GASEOUS HYDROGEN PRODUCTION

In the current United States economy, gaseous hydrogen is produced from natural gas, oil, coal, methanol, water, ammonia, and other miscellaneous raw materials. Hydrogen can also be recovered from a number of vent gas streams derived from chemical and petroleum refining processes. Raw material costs, investment life, operating costs, and on-stream requirements determine which of the above sources is most economical. Generally, markets for large volumes (50 million cubic feet per day or greater) of high-pressure, high-purity hydrogen are based on low-cost natural gas. Reformed natural gas currently sets the minimum cost of hydrogen in the United States economy. For medium-sized hydrogen requirements (5-30 million cubic feet per day), alternate sources such as purge or vent gas streams become more attractive.

LIQUID HYDROGEN PRODUCTION

Currently liquid hydrogen is made in the United States from hydrogen which has been produced by reforming natural gas or from hydrogen recovered from chlorine cell off-gas. In the past, liquid hydrogen has also been made from gaseous hydrogen produced by the partial oxidation of crude oil and natural gas, by reforming of propane, by electrolysis, and from refinery hydrogen-containing vent gas.

The liquefaction of hydrogen is an electricity-intensive process. Typically, the cost of electricity is as much as the cost of the gaseous hydrogen to be liquefied. While the safety of loading and shipping liquid hydrogen has been proven over a period of over thirty years, the shipment of liquid hydrogen is moderately expensive, especially due to shipping losses. Within the United States it is usually more cost effective to produce liquid hydrogen in large quantities at a location where power and feedstock costs are less expensive and then ship it to smaller users, even at distances of several thousand miles.

The subject of liquid hydrogen safety is a one which I can only touch on here. For further information on the well-established safety procedures followed by industry, Air Products is pleased to provide the committee a copy of a liquid hydrogen safety video, which we recently produced for the Chemical Propulsion Information Agency.

ALTERNATE TECHNOLOGIES

A hydrogen production technology that may become more economical is electrolysis of water. Electrolysis becomes attractive in locations where inexpensive feedstocks such as natural gas or vent gas streams are not available and where electric power is low in cost. Future development of photovoltaic cells may help to provide this low cost power. Production of hydrogen by electrolysis is perhaps the most benign environmental technology, as there is no production of waste gases such as carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2) or Oxides of nitrogen (NO_x). Photovoltaic electric power might serve a dual role. It could not only produce gaseous hydrogen, but could also provide the power to liquefy the gas.

Studies are currently underway under the NASP program to produce slush hydrogen, a mixture of 50% liquid hydrogen and 50% frozen hydrogen. This fuel is more dense than liquid hydrogen and thus permits 5% more fuel to be stored in the aircraft at time of take-off. The colder temperature and greater cooling capacity will also be used. Studies on the conversion of the molecular form of hydrogen from para-hydrogen to ortho-hydrogen will provide methods of producing additional useful refrigeration.

PRODUCTION DISTRIBUTION COSTS

A supply of liquid hydrogen would be required at many airports throughout the United States and the world. Should liquid hydrogen fuel in commercial aircraft become a reality, it is expected that virtually all of the above sources will be used somewhere, depending upon economics.

A breakdown of the typical current cost of liquid hydrogen shows there are many areas which must be addressed if the total supply cost is to become more competitive with jet fuel. These areas and their approximate costs are shown in Table I. There are obvious trade-offs between transportation/storage and low cost natural gas/electricity production locations.

TABLE I

		$/MMBTU
Gaseous Hydrogen Production,	Nat. Gas @ $2/MMBTU	3.35
	Capital & Labor Cost	7.02
Hydrogen Liquefaction,	Electricity @ $0.04/KWH	5.38
	Capital & Labor Cost	8.11
Transportation, 500 miles		2.55
Storage, two weeks	Capital Cost	1.38
Transportation, Storage, and Loading Losses, 40%		11.12
	Total	$38.91
Jet Fuel		$5.50

RESEARCH AND DEVELOPMENT

A number of potential research and development areas might have a significant impact in reducing the cost of liquid hydrogen. Some of these are:

1) Low cost production of electric power such as from photovoltaic cells. This power could be used for the production of the gaseous hydrogen and/or the liquefaction of this hydrogen.
2) Reduced cost of liquid hydrogen transportation, such as using unit trains.
3) Cogeneration of hydrogen and electric power using virtually any fuel.
4) Improved liquefaction cycles for large scale facilities. This might be directed towards the development of large, high speed centrifugal hydrogen compressors and expanders.
5) Alternate liquefaction technologies such as magnetic refrigeration.
6) Higher efficiency aircraft engines.
7) Studies to minimize loading losses of liquid hydrogen for the aircraft.
8) Centralized production of gaseous hydrogen with pipeline distribution to liquefaction facilities near airports.

DISCUSSION/CONCLUSION

There are many reasons to look towards liquid hydrogen as an aircraft fuel.

It is a clean fuel with no undesirable pollution by-products resulting from its usage. As an aircraft fuel it has the highest thrust per pound of all chemical fuels. It can be the next generation aircraft fuel, as jet fuel becomes less available and more expensive. The safety of loading and shipping liquid hydrogen has been proven over a period of more than thirty years. Gaseous hydrogen can be made from many different feedstocks. When fossil fuels are used to produce gaseous hydrogen, pollutants such as sulfur, carbon monoxide, carbon dioxide, and NOx are all concentrated and can be more economically disposed of than the combustion products from jet fuel. Furthermore, renewable sources of gaseous hydrogen, such as electrolysis of water using photovoltaic cells, are benign to the environment. There is currently an infrastructure in the United States for the supply of liquid hydrogen. When there is a need for liquid hydrogen to fuel aircraft, industry will be ready to supply it by using the current infrastructure within the United States. The major challenge is to improve the economics of production, distribution, and usage so that it is a viable energy source for aircraft Further research and development could help to reduce the cost of the supply and minimize the environmental impact of hydrogen production. Research and development activities for a commercial hydrogen-fueled aircraft should be coordinated with the hydrogen research currently underway for NASP, as there are many common interests. Many of the technologies associated with hydrogen production and ground facilities for hydrogen-fueled aircraft would be advanced under Title I.

Thank you for allowing me to testify before you today. I will be most happy to answer any questions or provide additional information if you desire.

Senator FORD. Thank you very much.

Mr. HAWKINS, would you like to proceed, and then I will have some questions for both of you.

STATEMENT OF WILLIS M. HAWKINS, SENIOR ADVISOR, LOCKHEED CORP.

Mr. HAWKINS. I, too, appreciate the opportunity of coming here, and I thank you for awakening me again. I was a participant in the hydrogen efforts for aircraft ever since its beginning, including the supersonic U-2 which caused the factory you just heard about, and it has been off and on, as you described it, for many, many years.

I must say editorially that the business of both DOE and NASA deciding which is the cheapest and then driving their programs around what is the cheapest fuel is the wrong way to get to the end. If we had decided on JP-4 on a cost basis, we would have never gotten to a jet transport.

So we really need somebody with focus that is beyond the focus of the economy, because until you get to using some of these fuels you will never receive the benefits of the economy that comes from manufacturing it for use.

The NASP program is a good program for helping hydrogen. It is going to help us with the cryogenic storage, which we know a great deal about already. It is going to help us reduce the volume of hydrogen, which is a problem but not a stopper. And it is going to help us with materials and pumps and all of that sort of stuff—the same sort of things that we had in pretty good shape in the early 1950s when we were doing the original program for trying to get a high-speed, very-high-altitude reconnaissance aircraft.

I support that completely. The only trouble with the NASP program is that it is such an expensive program, it is such a focused program that it also has hazards. Even Congress might say it is time to stop. We should be doing this research independent of those kinds of programs because when programs stop, so does the research, and we stop again.

I would like to assure that we had some kind of a steady program, a consistent program, just as you pointed out in your introduction, so that we would eventually get where we are going.

Actually, I support the statement of Mr. Serfass that we really need a transition program. I think this bill shows such a program, or at least asks for the plan for such a program. I hope that we do continue and I do support the bill.

Now I think that the decision and the planning for the demonstration, if there is one, is something that we ought to approach pretty carefully. I would guess that NASA and DOE, either one or in combination, will not be the good planners for this kind of a demonstration. We need to get the planners from outside of the government agencies, people who are entrepreneurs of one sort or another. You do need the enthusiast to set up plans like this.

For instance, you do not make a plan that demonstrates this only for the public. You have to demonstrate it to the man that is going to use it and is convinced that he can use it. That means, in the case of an aircraft, you have to have a demonstration that the aircraft operators, the commercial operators, for instance, need to know that they can use it. It is not only the public and it is not only the Congress that needs this demonstration; it is the user who is going to use it and will turn it into an industry.

Following up on that, I think from a budgetary standpoint you will find that the budgets we have talked about so far are insufficient to make a real demonstration if an aircraft is going to be the first demonstration. We will need to do it very carefully so that it can be certified and the FAA agrees that it can be certified. That I think is one of the real demonstration hurdles we will have to get over, and I hope that the plan includes such a process.

Actually, I would like to point out that from a demonstration standpoint the aircraft is sort of an awkward thing to do first. I think it is the kind of a device that utilizes hydrogen to its best advantage because it needs the high energy density and it does improve the performance.

But I think we will find in many places that there are other countries and other areas where hydrogen is about to be demonstrated for other uses. I point particularly to Canada, where they have got cheap hydroelectric power and they are making hydrogen and they are planning on making a lot more hydrogen. They have fuel cells to drive automobiles today and they have been sold to Japan and Germany and to France.

I think that we may get caught up if we do not think our way through the demonstration, aircraft and otherwise, as soon as possible.

With respect to the safety, we went by that pretty fast in the previous testimony. The studies that were made for NASA ten or more years ago were made by several people, and it was demonstrated that hydrogen was the safest fuel for aircraft. I think other demonstrations have taken place where they use hydrogen even in homes. That is reported on in just this recent hydrogen meeting that was held here in Washington.

It appears to be better than most fuels, mostly because it goes up. You know where hydrogen is going to go when it is loose. The fuels that spread around on the ground are the fuels that are very disastrous. So they burn ten times as long as hydrogen and they burn on the ground where everybody else is.

So I think we can have a gain in safety if we use hydrogen in the future. Thank you.

[The prepared statement of Mr. Hawkins follows:]

WILLIS M. HAWKINS, SENIOR ADVISOR
LOCKHEED CORPORATION
CALABASAS, CALIFORNIA

January 28, 1981

LIQUID HYDROGEN (LH_2) FOR AIR TRANSPORTS

Conventional petroleum-base fuel will not be economically available for very long in the future. Conservation, even though necessary, does not produce fuel for expanding real needs. The supply/price escalation will not improve. Alternative fuels must be developed for all fuel needs. It appears possible that air transport could be the pioneering need to develop one of the most promising of these alternatives - LH_2.

Why Just Air Transport?

The air transport industry is particularly concerned because it has never commanded a high priority in times of fuel shortages, and because it requires that a common fuel be available anywhere in the world. Synthetic jet fuel, produced from coal, oil shale, or tar sands, can provide an interim answer. However, these resources are neither universally available nor infinite in capacity; therefore, synjet cannot be an acceptable solution for long. It is urgent that an aggressive program be initiated immediately to develop a more satisfactory long-term solution.

Liquid hydrogen (LH_2) has been shown to be a most attractive candidate. Eight years of NASA-funded studies have provided evidence that LH_2-fueled aircraft offer the following advantages:

- global availability
- improved safety
- minimum pollution
- reduced noise
- potential cost saving
- reduced total energy demand
- better airport compatability

Why Worry Now?

Development of an LH_2 infrastructure and aircraft capability will take from eight to twenty years. This requires at least the following, not all of which can be done in parallel:

- develop LH_2 production technology and airplane and airport technologies -- three years
- demonstration LH_2 plant -- two years
- demonstration aircraft -- three years
- build LH_2 fuel production facilities -- five years
- convert existing aircraft and certify -- five years
- design, build and certify new aircraft -- eight years

Assuming a high priority program based on conversion of existing aircraft, it is expected LH_2-fueled commercial aircraft could carry their first passengers in eight years. A business-as-usual program to design and build new advanced design aircraft would take 16 to 20 years.

Petroleum industry consensus is that worldwide crude oil production will start to become critical about 1990, assuming no further disruption in the Middle East.

Why Not Military First?

Major potential advantages do exist for the use of LH_2 in military aircraft. These are most apparent in long range transports and helicopters and the fuel promises very long-range (or duration) missions beyond those possible today (communications, surveillance, on station relay, etc.). Less obvious is the very real potential for long range supersonic combat aircraft.

The military will have priority on fuel if military action is needed. Military developments can have much shorter lead times due to the nation's willingness to accept risk in such developments. This suggests that a major fuel change for all military aircraft can be postponed. Finally it would be necessary to select early military missions that are based in the United States, even in an emergency, to avoid the necessity of creating a worldwide LH_2 logistic system for initial use.

It should be emphasized that military developments may not be adequate to assure civilian certification authorities and government commercial transport mentors that such a system may be introduced safety into commercial services.

What Does the Rest of the World Think?

Many professionals concerned with future air transport gathered in Stuttgart, Germany in the fall of 1979 to discuss the potential for LH_2 as an aircraft fuel and to consider the alternatives (including synthetic jet fuels) which could replace petroleum. The experiences of worldwide authorities were compared and thoughtful members of the airlines as well as experienced airport operators considered the implications of the new designs, the added operator requirements and the potential costs. The symposium concluded that a future of such promise must be pursued and that the potential of economic advantage for LH_2 was real.

One major concern expressed by several non U.S. members was that coal as a source of world energy not only created new environmental problems but imposed a new minority of "have" nations on the world. Thus LH_2, which could be created using many universally available energy sources such as nuclear, hydroelectric, solar, wind and deep ocean temperature differences offered substantially more independence to "non coal" nations and also provided a sounder basis for worldwide fuel availability -- essential to successful international transport systems.

The participants in this international program were sufficiently concerned with the problems of a future that contained only synthetic petroleum fuel that they formed on ongoing activity which has outlined R&D programs and is attempting to start such programs within participating nations to bring LH_2 into realistic contention.

What About Cost?

Early estimates of cost in creating and liquefying hydrogen discouraged many pioneer proponents who recognized its advantages in energy density, non pollution, and safety. Even further inhibitions were uncovered by contemplating the cost of infrastructure changes if a total hydrogen civilization evolved. These attitudes pervaded and still exist in the agencies responsible for government sponsored research that could accelerate the creation of adequate hardware. These same agencies could also explore concepts and methods which would lower the cost barriers to a truly energy rich future.

In the face of these concerns NASA sponsored early studies that built a real foundation, confirming LH_2 advantages in air transport. These studies also explored the costs and configurations of airport conversions. The next logical step, an experimental R&D program, has not been taken by NASA because the parallel programs to produce the fuel have not been adequately sponsored by DOE. Similarly, no major effort has been initiated to prepare for certification (DOT-FAA).

Due to recent legislation and the cooperative efforts of a number of utilities a modern method of creating hydrogen has been demonstrated, and in a recent proposal to DOE this system was to be used as a basis for studying a pioneer LH_2 airline. The costs of LH_2 are shown in this proposal to be equivalent to present day jet fuel costs for airlines -- a major breakthrough. These costs are summarized in the attached appendix. The proposal was rejected because there was no demand for such fuel by the operating airlines and no transport aircraft existed that needed it. Thus one concept for major improvements in energy availability has fallen through the wide abyss between government agencies.

The cost of fuel is not, of course, the total cost barrier, the conversion of the infrastructure may be of even more immediate concern since it represents a large investment that isn't normally amortised in a commercial sense. The infrastructure change for transport aircraft is modest compared to a total change for all energy users but it is still large. This front money is needed before even pioneering transport operations could start. The industry did make the conversion to jet fuel from gasoline in a remarkably short time but the primary cost was in aircraft where commercial cost recovery is well understood.

A few numbers are useful to place the costs in scale. Sixteen world airports are estimated to provide the base for nearly 40% of the passenger traffic over 1500 miles range in 1990. The advantage of LH_2 in cost per seat mile would pay for half the amortization of the airport investment in 15 years. An airport improvements tax of only 4/10ths of a cent per passenger mile would complete the amortization. This is only one half of the airport improvement tax we once charged in the U.S. In a similar vein our current surplus in the airport improvement fund would equip all of the United States airports in this long range traffic family.

What Should Be Done Now?

It is suggested that the committees of the House and Senate hold hearings to determine whether or not the United States is ignoring a promising long range solution for an alternate fuel which could be pioneered to advantage in the air transport industry.

Inherent in such hearings should be an exploration of agency responsibilities for R&D that may be preventing the pursuit of promising long range solutions to the energy problem.

APPENDIX

A COST BASIS FOR COMPETITIVE LIQUID HYDROGEN *

In September 1980, a preliminary analysis was made under the direction of the General Scientific Company, a wholly owned subsidiary of Pacific Lighting Corporation, to determine the cost of producing LH_2 at a plant suggested for construction near Barstow, California. The plant design was to be based on use of the Institute of Gas Technology continuous steam-iron process for converting coal and water to hydrogen. It was sized to produce 200 tons of LH_2 per day. The LH_2 was to be carried to the Los Angeles International Airport (LAX) by rail tank car to be used as fuel for commercial transport aircraft.

The conservative preliminary analysis showed that the LH_2 could be delivered to storage tanks at LAX at a cost of only $6.93 per million Btu. This should be compared with a wholesale price of $7.73/M Btu for aviation grade kerosene (Jet A)as delivered to LAX in September 1980. With this price advantage, plus the fact that LH_2-fueled aircraft operate more efficiently because of their reduced weight than do conventionally-fueled aircraft, airlines would realize a significant cost benefit. In addition, use of coal-derived LH_2 would eliminate concern about fuel availability in times of oil shortage.

The extremely attractive price of LH_2 was due primarily to the large quantity of high temperature/high pressure spent producer gas which is an important product of the IGT process, in addition to the primary product, gaseous hydrogen. In the subject analysis, the spent producer gas was to be used to produce electricity in a cogeneration process. The proposed plant at Barstow would consume approximately 7000 tons of coal per day and would produce 211 megawatts of electric power in addition to the 200 tons of LH_2.

By federal law, utilities in the United States are required to buy surplus electric power produced in their districts at a rate equivalent to "avoided" costs. The purpose of the law is to reduce the amount of oil which must be imported annually. Accordingly, the sale of cogenerated electric power produced by the subject plant in excess of that required for inplant operations can be sold and thus significantly reduce the cost of the hydrogen.

The rate to be paid for the surplus electricity is established by the public utility commission in each state, commensurate with local utility base load costs. Last summer these rates ranged from 4.52 cents per kilowatt hour to 11.77 cents/kWh in 25 major U.S. cities. The rate established for Southern California Edison Company in Los Angeles for October 1980, was 7.145 cents/kWh.

The high price of oil and the resultant high cost of electrical power has made the IGT continuous steam-iron coal gasification process very attractive for producing hydrogen economically. As the price of oil used by electric utilities in their base load plants increases in the future, the price of hydrogen will benefit correspondingly.

Throughout the subject cost analysis a conscious effort was made to keep the basis as realistic as possible. Where uncertainty existed regarding options, the conservative value was selected.

The attached table lists a number of the significant factors which entered into the calculation of the cost of LH_2 delivered to the Los Angeles International

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*Contained in a proposal to DOE September 30, 1980 by the General Scientific Co. to studv the economic feasibility of building a plant and modifying aircraft to operate a pioneer LH_2 fueled airline.

Airport. Capital and operating costs of the liquefaction plant were taken from NASA TM 80155 and scaled as appropriate.

It should be recognized that an additional cost of between \$1.00 and \$1.50/10^6 Btu should be added to the above delivered cost of LH_2 to LAX to account for the cost of storing the fuel at the airport and delivering it into the aircraft tanks. This would make the delivered cost of the LH_2 into the aircraft \$7.93 to \$8.43/10^6 Btu. Converting into more common terminology, \$8.00/10^6 Btu is equivalent to Jet A fuel at about \$1.00 per gallon.

As a supplementary point, it should also be recognized that a typical long-range LH_2 fueled transport requires only 84 percent of the energy needed by a conventionally fueled aircraft to fly its design mission.

Table 1

COST BASIS FOR THE PROPOSED BARSTOW LH_2 PLANT

Plant Design Capacity	200 TPD LH_2
Selected Process	IGT Continuous Steam-Iron
Coal	
Type	Montana Subbituminous
Heating Value	8654 Btu/lb
Cost (at mine)	$10/ton
Transport cost	2.3¢/ton mile
Delivered cost at Barstow	$2.00/$10^6$ Btu
Water Cost	60¢/1000 gal.
Useful life of Vanes and Blades of power recovery turbines	1 year
Plant Life	20 years
Plant Stream Factor	90 percent
Financing Basis	Utility
Gaseous H_2 cost	$2.05/$10^6$ Btu
Loss of GH_2 in liquefaction process	12.3 percent
By-Product Power Credit	211 MW sold at 7.145¢/kWh
Deuterium Oxide (D_2O) credit	$1.62/$10^6$ Btu
LH_2 cost at Barstow plant	$5.54/$10^6$ Btu
Rail transport LH_2 to LAX	$1.39/$10^6$ Btu
LH_2 cost delivered to LAX	$6.93/$10^6$ Btu

Lockheed Corporation

Burbank, California 91520

Willis M. Hawkins
Senior Advisor

30 July 1981

Dr. Henry L. Stadler, Director
Office of Vehicle and Engine R & D
CS8
Department of Energy
Forrestal Building
Washington, D.C. 20585

Dear Dr. Stadler:

It is my understanding that the Department of Energy, in an effort to respond to Administration desires to depend on the resources of the private sector, is considering the elimination of funding for synthetic fuel development in 1983. The Lockheed Corporation has studied the potential of alternate fuels for air transport and military aircraft and has related these studies to other elements of the economy depending on the same basic energy resources. Based on the advantages of some of the alternatives studied and the realization of the difficulties inherent in coordinating many disparate commercial, political, and regulating entities, we cannot avoid the conclusion that government leadership and participation is essential to achieve the advances afforded by our technological base, and may be crucial to the future economic health of our nation.

First, some general considerations:

1. There is a clear need for development of alternative fuels.

   Despite increased exploration for new domestic sources of crude oil, as well as increased emphasis on development of more efficient recovery methods, no responsible authority in the petroleum industry predicts the United States can even approach self sufficiency. We will need to continue importing substantial quantities of oil. Without an aggressive alternate fuel program, the United States will be vulnerable economically, politically, and militarily. The rate of development and the creative use of advanced concepts cannot rationally be accelerated for national purposes by private funds since the return on investment for such acceleration and the risks assumed are beyond the capacity of the private sector.

2. Many energy sources must be developed.

   Development of all of our various significant energy resources will be required to meet the needs in the next few decades, even with serious efforts in conservation. Principal among the energy sources which could be developed in the immediate future are coal, shale, and nuclear fission to supplement dwindling domestic oil and natural gas. Equally important in local areas but with modest impact on our total domestic needs are hydropower, geothermal, wind, solar, OTEC, and biomass. This multiplicity of new concepts will demand private development funds far greater than history suggests, and most such programs will impose new risks to reasonable return on investment.

3. Different energy users will employ different fuels.

   Depending on the application and the energy source which may be available, different energy users may satisfy their requirements by different fuels. For example, stationary power plantsin factories or public utilities can be provided with whatever fuel may be available locally. The choice may, of necessity, be based on transition costs rather than ultimate costs of the energy itself.

   The choice of fuel for highway vehicles is constrained by the requirement that an acceptable alternative be available anywhere throughout the country from thousands of local retail outlets. Vehicles from Maine must be able to operate in California. Local investment, or single company or even regional investment, will not solve the problem.

   Aircraft represent a unique dilemma since they require a high energy density fuel which can be available at airports anywhere in the world. Global availability is a prime requisite that may be more important than local cost per BTU.

Some of these user sectors will require substantial support in development of the alternative fuel best suited to their needs. The air transport industry is a case in point. Although the following remarks are directed primarily to the need for development of alternative fuels for air transport, they may bear upon the broader need for a crude oil alternative for all purposes.

The candidate fuels for aircraft application, we believe, are synthetic aviation grade kerosine (synjet), liquid hydrogen (LH_2), and liquid methane (LCH_4). Of these, on the basis of nearly eight years of studies for NASA, LH_2 has been shown to provide:

- o Global availability. It can be made from water using any energy source. Fossil resources are not required.
- o Superior design and performance. LH_2 aircraft are lighter weight, have shorter wing span, are quieter, and produce less pollution.
- o More efficient utilization of resource energy. If all three candidate fuels are made from coal, less coal is required to make the fuel for an LH_2-fueled airplane to fly a specific mission.
- o Lower cost. Direct operating cost can be at least equivalent and can be significantly lower if advanced technologies based on LH_2 thermal content are used. These advances cannot be achieved with the other alternatives.
- o Improved safety. In event of an otherwise survivable crash, passengers and surroundings will be exposed to less hazard if LH_2 is the fuel.

It may be asked, "If liquid hydrogen shows so much promise, why doesn't the aircraft industry proceed without waiting for government support?" These points are pertinent:

1. The course of least investment is to continue using the conventional fuel until it is entirely uneconomic or unavailable. The amount of import fuel is not a private industry responsibility, only cost.

2. There is no profit incentive for any industry segment per se, to undertake the development without parallel development in other segments. The change to liquid hydrogen fuel, as an instance, requires across-the-board involvement of fuel producers; aircraft, engine, and component manufacturers; airlines; airport operators; and government regulatory and certifying agencies.

3. If the air transport industry is the pioneer user of hydrogen, it will bear the burden of much research and development which will ultimately benefit other potential users with no hope for recoupment. In addition, ultimate requirements of various certifying agencies will not be known until after significant research, development, and demonstration has been accomplished. The uncertainty of these associated costs precludes the use of private funds.

4. These considerations added to the uncertainty of when alternatives will be needed inhibit the investment to perform the research, development and demonstration to qualify the technology. To design and build production capability, would expose industry to inordinate financial risk for inadequate return.

5. The benefits to society will exceed the costs but these cannot be counted as profits. The potential benefits to the United States in the use of liquid hydrogen as fuel for transport aircraft are:

   - more efficient use of resources
   - improved environment
   - new employment possibilities
   - new products and services
   - improved trade balances
   - compatibility with international partners who have no coal resources.

6. The effort requires international cooperation and coordination. Although local airlines can convert to liquid hydrogen and achieve benefit, the principal advantages will be realized only when the major fuel users, i.e., the international carriers and domestic trunk airlines throughout the world, make the conversion. The combined efforts of governments and industry will be required to bring about a change of this magnitude.

In summary, in the aircraft application of LH_2 as an alternate fuel, we have a situation in which the existence of a clearly superior fuel is recognized, the need for initiation of development of a replacement for the existing fuel is evident, and there is not incentive to finance the technology development required for such an alternative to be brought to the level where competitive demonstrations can be made with conventional synthetic fuels.

At the present time an impasse exists between two U. S. government agencies which completely forestalls even the smallest constructive action. NASA agrees with the technical evaluation of the LH_2 potential but believes that a NASA development and demonstration program will not be politically supported until scarcity drives fuel prices beyond reason. Since synthetic Jet A requires no changes to the aircraft, this view doesn't preclude the use of an alternative, it just excludes competitive alternatives to synthetic Jet A. Furthermore, NASA does not plan to undertake active development of engine technology to use LH_2 until DOE initiates development of fuel manufacturing and processing technologies. On the other hand, DOE has not supported development of LH_2 manufacturing processes because there is no current demand for the fuel from the air transport industry or NASA.

This decision by exclusion continues despite a recommendation for positive action by the National Research Council referring to hydrogen use in the total economy. Their report, "Hydrogen as a Fuel," dated 1979, contains the following statement on p. 2 of the Summary:

"...there is a need for a well conceived R&D program to study some of the basic problems that may constrain hydrogen's entrance into the national fuel economy. Specifically:

- Basic exploratory research on innovative concepts related to the production, transmission, distribution, storage, or use of hydrogen should be pursued even if near-term market needs cannot be identified.

- The federal program should be complete enough to provide a data base that will enable sound evaluations and decisions to be made in the future about more costly development and demonstration programs.

- Such large-scale system development and demonstration decisions should be deferred until a market need is identified and it is established that the private sector will not undertake the necessary effort.

- Particular attention should be given to research seeking to understand and resolve potential safety problems associated with introducing all phases of the hydrogen production-use chain into the energy complex."

Finally, a word about the author. I have served Lockheed in many technical capacities for 44 years, achieving the position of Senior Vice President-Science and Engineering for the Corporation and election to the Board of Directors. I also served as President of the California Company — the company responsible for the L1011 transport family and the NASA alternate fuel studies discussed in this letter. My association with the government includes a stint as Assistant Secretary U.S. Army R&D, and I have served NASA, DOD, DOT, and OTA in a number of advisory roles. I now serve on NASA's Advisory Council. Upon retirement from Lockheed in 1980, I was asked to serve the Chairman and the Board as a Senior Advisor — a role which I continue to fulfill. I believe this background qualifies me to have opinions that may be worth considering. I hope they convey my conviction that for lack of a modest national R&D program we may be excluding from consideration an alternate fuel that could fill our need for the 21st century.

My desire is to help persuade the Department of Energy to continue development of synthetic fuel in general and liquid hydrogen in particular.

I know that Lockheed Corporation considers the subject to be of vital importance. Please call me on (213) 847-6623 if I can help to clarify any of the points that have been made or assist in any program plans.

Yours sincerely,

Willis M. Hawkins

Willis M. Hawkins

Senator **Ford**. Thank you, Mr. Hawkins.

Let me ask you, Mr. Moore. You apparently have had experience with the delivery of hydrogen, both barges, 18- wheelers, and pipelines.

Mr. **Moore**. Yes.

Senator **Ford**. On the pipeline, what was the end use? How long was the pipeline? Was that just a test?

Mr. **Moore**. The pipeline system that we had in West Palm Beach, we had about a mile out to our storage tanks. Then we had an additional mile from the storage tanks to the Pratt & Whitney test facilities where they would test the engines. We always kind of got a kick out of it. It would take us two, three, four days to fill our tanks; they would start one of these engine tests, and whoosh, it was gone.

We did that. We have been involved in studies for the piping and what have you which would be needed at Cape Kennedy for loading the vehicles there, and that is about a mile's worth. We are not talking much more than several miles. Usually then it becomes more economical to switch to trailers or to rail cars.

Senator **Ford**. What about barges?

Mr. **Moore**. Barges. The prime end use on the barges we used were shipping about 50 miles from the plant site up to Stennis. It was originally envisioned to use those barges to take them as far as Cape Kennedy. This, I do not believe has ever been done, partially because of docking and environmental concerns with the manatee and what have you.

That was to have been like a 1,000-mile trip. It has been used many repeated times on the 50-mile. In that particular case, it is a dual use of the barge as a shipping medium and also as a storage medium at the test facility.

Senator **Ford**. You say that you could take the barges to Canaveral but for environmental and people problems. What would be the environmental and people problem at Canaveral with the barge operation?

Mr. **Moore**. The main problems that I have heard, talking with other people, they are worrying about the manatee getting run over and hurt by the propellers of the barges. As far as environmental spills and things like that, no problem. They are really worried about the hazards to the wildlife.

Mr. **Hawkins**. I would like to add to the answer. There are two different problems with transportation of hydrogen, and I should say two different ways. If you are going to transport it as a gas, the pipeline is the best way to do it. If you are going to transport it as liquid hydrogen, you have to do it differently and the trucks and the barges are the right way of doing it.

There is a 200-mile hydrogen gas line that has been operating in Germany since World War I. It serves their industry and it is a well-known technology. You just have to pick the right materials for the pipeline. It is just like natural gas.

Mr. **Moore**. I would like to just further comment. As a company, we operate 140 miles of hydrogen pipeline, both in the United States and in Europe. So we are comfortable with that method of transportation. My comments were really on liquid.

Senator **Ford**. Mr. Hawkins, let me ask you this. You talked about Canada in your statement and you referred at least twice, maybe more times than that, to their hydroelectric power.

I go back to my question of the previous panel when I said does this not mean that we really need a very, very low-cost source of electricity. So hydro is an inexpensive source or less so than other. Is that the reason Canada has been able to move faster, because they do have hydroelectric?

Mr. **Hawkins**. That is right. They do have a lot of hydroelectric power, and at the source it is really pretty cheap. Our problem in the United States is that we charge our electricity on the basis of where it is transported to. So if you can make the hydrogen right at the source of the hydroelectric power, it is substantially cheaper and depends upon what the cost of transportation is.

Now I remember ten years ago we made a study of this and it was determined that it would be better to transport the hydrogen by hydrogen pipeline from a source that was cheap if you were transporting it over 125 miles and further, rather than make electricity and transport the electricity and then make the hydrogen, because at that point the electricity got to be more expensive and the hydrogen got to be more expensive.

It was better to make the hydrogen right at the hydroelectric source and then transport the hydrogen by pipeline.

Senator **Ford**. How large would one of these be—how many megawatts? How big should it be?

Mr. **Hawkins**. Well, heavens, I do not know. It is a matter of demand. In their particular case, they have almost infinite power up in Nova Scotia and nobody has come to Nova Scotia to use it. So Canada was interested in trying to use that kind of power.

Senator **Ford**. Would you have a ballpark size? Maybe you could get it too small or you could get it too large. I do not know whether you can have it too large or not.

Mr. **Hawkins**. I do not think anybody really knows at this point. But the fact is that Canada did at one time commit for a demonstration program, which we had proposed ten or 12 years ago. They proposed to deliver hydrogen—as a matter of fact, it was liquid hydrogen—to New York for the same dollars per BTU, per million BTUs, as JP-1.

Now I think JP-1 has gone down since then, but in those days we thought it was going to go up by factors of two or three. And they were equivalent to JP-1 in those days. So the economy of liquid hydrogen, if it is properly produced in the right place, has been computed at least to be pretty close to JP-1 for aircraft.

Senator **Ford**. You said that Canada has now sold liquid hydrogen to Japan and France?

Mr. **Hawkins**. No. They have sold the fuel cells that will use hydrogen. Now they have got two versions of this fuel cell, one that uses natural gas but has its own conversion at the fuel cell. It converts the natural gas to hydrogen and then uses hydrogen in the fuel cell. So it is all part of the automotive power plant.

But that is the wrong way of doing it, if you can get hydrogen directly, because you can take the conversion out of the automobile and use hydrogen directly.

Senator FORD. We have some fascinating opportunities here, or possibilities.

MR. HAWKINS. I think it is going to catch up with us if we do not get doing something.

Senator FORD. As I asked the previous two witnesses, it is obvious that the Departments will be controlled by OMB. Mr. Darman becomes the czar instead of the director of the Office of Management and Budget.

Are the monies and the manner in which they are designated in this bill out of line? Can it be useful to you? Do we need more, or can you get by on less? Give me something to argue with those who say it is too much or too little.

Mr. HAWKINS. For the purpose of producing a plan, which is the way I read the bill——

Senator FORD. That is correct.

Mr. HAWKINS [continuing]. I think it is adequate, useful, and absolutely necessary. I support it.

Senator FORD. Mr. Moore, do you have a comment as it relates to the financing in the bill?

Mr. MOORE. I am not that familiar with the costs, although I am in an economic evaluation position. I would say that what I have seen appears to be adequate. A lot of depends upon how much research you want to do and how much direction.

Senator FORD. Apparently we are looking at so many other things we are allowing the base of our growth and stability and strength to go wanting, if that is the word, and we need to turn inwardly and look at those things that have made us the strong nation that we are.

On the other side of the coin, when we do all the research and development, we have a hard time getting it into the marketplace.

You gentlemen are mighty nice, and I do appreciate your coming today. If you have anything that you can think of that maybe we should have as input into this hearing, if you will send it to us, we will be delighted to put it into the record and hopefully we can get to the markup on this bill fairly soon.

One question, though, before we go. Mr. Hawkins, you said we ought to have outside advisors, including commercial operators, I believe you said. How large and from what fields should we have them? I do not want companies or anything, but just give me some fields of endeavor that you think would be important.

Mr. HAWKINS. Well, all I was suggesting was that if this bill does pass, and if these funds are made available to agencies such as the DOE and NASA, I trust that they will, instead of making the studies on what the demonstration ought to be, that they will seek proposals from outside of those agencies in order to figure out what is the most far-seeing proposal that you could have to make a demonstration because I do not think in their internal staffs they have that much vision.

Senator **Ford**. What you are referring to is a joint venture.

Mr. **Hawkins**. That is right.

Senator **Ford**. Well, I think that will do it for the day. I am grateful. We have moved right along, got a lot of good information, and hopefully we will be seeing some fruits of our labors here today.

This hearing is adjourned.

[Whereupon, at 10:59 a.m., the hearing was adjourned.]

APPENDIX

RESPONSES TO ADDITIONAL QUESTIONS

Department of Energy
Washington, DC 20585

April 24, 1990

The Honorable Wendell H. Ford
Chairman
Subcommittee on Energy Research
and Development
Committee on Energy and Natural Resources
United States Senate
Washington, D.C. 20510

Dear Mr. Chairman:

On March 30, 1990, J. Michael Davis, Assistant Secretary of Energy for Conservation and Renewable Energy, gave testimony before your subcommittee on Title I of S.639, The Hydrogen Research and Development Act.

Following that hearing, you submitted written questions for our response to supplement the record. Enclosed are the answers to those questions.

If you have any questions, please have your staff call Barbara Campbell on 586-8687. She will be happy to assist.

Sincerely,

Jacqueline Knox Brown
Assistant Secretary
Congressional and Intergovernmental Affairs

Enclosure

QUESTIONS FROM SENATOR FORD

Hydrogen

Question 1a: Please provide the Subcommittee with summary tables showing the budget for DOE mission research on hydrogen and where this research money is being spent for fiscal years 1989 and 1990 and as proposed for fiscal year 1991.

Answer: The mission research is carried out in a number of research laboratories. These span the Federal laboratories and universities. For example, the principal renewable energy hydrogen research effort is performed at Texas A&M University, Hawaii Natural Energy Institute, Florida Solar Energy Center, and the Clean Air Institute of the University of Miami. Other smaller efforts are carried out at the Solar Energy Research Institute, Brookhaven National Laboratory, and Syracuse University. The details of all of the mission related research are listed in the Hydrogen Energy Coordinating Committee Annual Report-Summary of DOE Hydrogen Programs for 1989. No significant changes are expected in FY 1990 and FY 1991 except that the funding requested for renewable energy programs is to be used primarily for competitive solicitations. With respect to the mission related funding, I would be pleased to provide a table for the record.

TABLE

DOE Hydrogen Mission Related Research Funding

(dollars in millions)

Research Area	FY1989	FY1990	FY1991
Basic Energy Sciences	0.3	0.3	0.3
Renewable Energy	2.8	2.5	2.5
Fossil Energy	1.9	1.9	0.3
Fusion Energy	0.0	0.0	0.0
Inertial Fusion	0.0	0.0	0.0
Weapons Testing	0.0	0.0	0.0
Other Offices	0.2	0.93	0.4
Totals	5.2	5.63	3.5

Question 1b: Please do the same for DOE's non-mission hydrogen research.

Answer: The non-mission research is carried out in a number of research laboratories. These span the Federal laboratories and universities. For example, the photochemical generation of hydrogen research of the Office of Basic Energy Sciences was carried out at 4 DOE laboratories, the Notre Dame Radiation Laboratory, the National Institute of Standards and Technology and 31 Universities in FY 1989. The details of all of the non-mission related research are also listed in the Hydrogen Energy Coordinating Committee Annual Report-Summary of DOE Hydrogen Programs for 1989. No significant changes are expected in FY 1990 and FY 1991. With respect to the non-mission related funding, I would be pleased to provide a table for the record.

TABLE

DOE Hydrogen Non-mission Related Research Funding

(dollars in millions)

Research Area	FY1989	FY1990	FY1991
Basic Energy Sciences	16.2	16.7	17.0
Renewable Energy	0.0	0.0	0.0
Fossil Energy	0.0	0.0	0.0
Fusion Energy	5.3	5.3	5.3
Inertial Fusion	1.7	1.7	1.7
Weapons Testing	8.5	9.9	9.9
Other Offices	0.0	0.0	0.0
Totals	31.7	33.6	33.9

Question 2: Please explain or provide analysis showing how to compute the energy balance in the production of hydrogen in the principal methods under use or under study for hydrogen production. Also provide an analysis of the production of CO_2 or other important pollutants under each of these methods.

Answer: 98% of the hydrogen produced today is by the steam reforming of natural gas. Steam reforming has an overall energy efficiency of 66%. That is, it takes about 1.5 Quads of natural gas to produce 1 Quad of hydrogen. Currently, the principal remaining process is the electrolysis of water which is used where high purity hydrogen is required. To determine the fuel cycle energy efficiency of electrolytically produced hydrogen, the efficiency of electric generation must be multiplied by the efficiency of electrolysis. The electrolysis efficiency is about 75% while electric generation efficiency depends on the fuel used. If the current electric grid is the basis of electricity then the generation efficiency is about 33% and the product of the 2 efficiencies is about 25%. That is, it requires about 4 Quads of energy to electrolytically produce 1 Quad of hydrogen. If state-of-the-art photovoltaic electricity were to be used, the overall efficiency would be about 10%. The Office of Fossil Energy estimates that the efficiency of conversion of coal to hydrogen will be marginally less than the efficiency of converting natural gas to hydrogen or slightly less than 66%. The renewables program is conducting research on a number of direct systems of splitting water. It is too early in the research to estimate the potential efficiencies of these systems.

I would be pleased to submit a table for the record to illustrate the range of estimated carbon dioxide emissions.

TABLE

Carbon Dioxide Emissions of Hydrogen Production Processes

Process	lbs CO2/lb H2
Steam Reforming of Methane	11.0
Coal Gasification	18.6
Electrolysis by source of electricity	
Coal	44.0
Nuclear	0.40
Renewable	0.23
Biomass steam reforming w/new growth	0.00*

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*At the instant of conversion, biomass and coal produce the same amount of CO_2. The regrowth of biomass in the next 5 to 10 years reabsorbs the amount of CO_2 produced in the conversion process.

Question 3: **Please provide the Subcommittee with estimates of hydrogen costs (in $ per million BTU) for the various production methods, showing the sensitivity of these costs to the important factors in the cost calculation.**

Answer: The cost of hydrogen from steam reforming of natural gas is between $6 and $11 per million Btu. This cost is sensitive to the price of natural gas and to the location of and infrastructure surrounding the plant. According to figures provided by Air Products and Chemicals, Inc., the price of delivered hydrogen is estimated to be $10.37 per million Btu for production, $13.49 per million Btu for liquefaction, $2.55 per million Btu for 500 miles transport, $1.38 per million Btu for 2 weeks storage, and $11.12 per million Btu for boiloff and losses, or a total of $38.91 per million Btu. The estimate assumes a starting natural gas cost of $2.00 per million Btu. The cost of electrolytic hydrogen varies depending on the cost of electricity and the size of the plant. In bulk quantities, it ranges from $20 to over $100 per million Btu. A single cylinder of compressed hydrogen costs about $228 per million Btu. The current estimated cost of photovoltaic electrolytic hydrogen is $82 to $165 per million Btu depending on the location. The cost after both the DOE photovoltaic (6 cents per kWh) and electrolyzer goals (85% efficiency) are met would be $22 per million Btu.

Question 4. A principal aim of S. 639 is to develop, in consultation with a broad spectrum of interests, a plan for hydrogen research and development activities (see sections 102 and 104). What sort of plan is DOE using now to guide its mission and non-mission hydrogen research?

Answer: Presently, DOE uses the Hydrogen Energy Coordinating Committee and the results of peer reviews by individuals from industry and academia for planning both mission and non-mission hydrogen programs. In addition, DOE is preparing a multi-year plan for guiding its renewable hydrogen program.

J BENNETT JOHNSTON LOUISIANA CHAIRMAN

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United States Senate
COMMITTEE ON
ENERGY AND NATURAL RESOURCES
WASHINGTON, DC 20510-6150

April 3, 1990

The Honorable J. Michael Davis
Assistant Secretary
Conservation & Renewable Energy
U. S. Department of Energy
Washington, D.C. 20585

Dear Mr. Davis:

I want to thank you for your testimony on March 30, 1990 before the Subcommittee on Energy Research and Development on S. 639, to establish a hydrogen research and development program.

As a follow-up to that hearing, I am enclosing questions to be provided for the printed hearing record. I am requesting that the answers to these questions be provided to the Subcommittee no later than April 23, 1990.

If you have any questions concerning this request, please contact Ben Cooper or Cheryl Moss at 224-7569.

Sincerely,

Wendell Ford

Wendell H. Ford
Chairman, Subcommittee on Energy
Research and Development

Enclosure

FOLLOW-UP QUESTIONS

March 30 Hearing on S.639
Hydrogen Research and Development

Subcommittee on Energy Research and Development
Committee on Energy and Natural Resources
U.S. SENATE

1. Please provide the Subcommittee with summary tables showing the budget for DOE mission research on hydrogen and where this research money is being spent for fiscal years 1989 and 1990 and as proposed for fiscal year 1991.

Please do the same for DOE's non-mission hydrogen research.

2. Please explain or provide analysis showing how to compute the energy balance in the production of hydrogen in the principal methods under use or under study for hydrogen production. Also provide an analysis of the production of CO2 or other important pollutants under each of these methods.

3. Please provide the Subcommittee with estimates of hydrogen costs (in $ per million BTU) for the various production methods, showing the sensitivity of these costs to the important factors in the cost calculation.

4. A principal aim of S.639 is to develop, in consultation with a broad spectrum of interests, a plan for hydrogen research and development activities (see sections 102 and 104). What sort of plan is DOE using now to guide its mission and non-mission hydrogen research?